

FIELD GUIDEBOOK

Prepared for Annual Field Trip, Coal Geology Division,
Geological Society of America
Milwaukee, Nov. 9-10, 1970

DEPOSITIONAL ENVIRONMENTS IN PARTS OF THE CARBONDALE FORMATION- WESTERN AND NORTHERN ILLINOIS

Francis Creek Shale and Associated Strata
and Mazon Creek Biota

by

W. H. Smith

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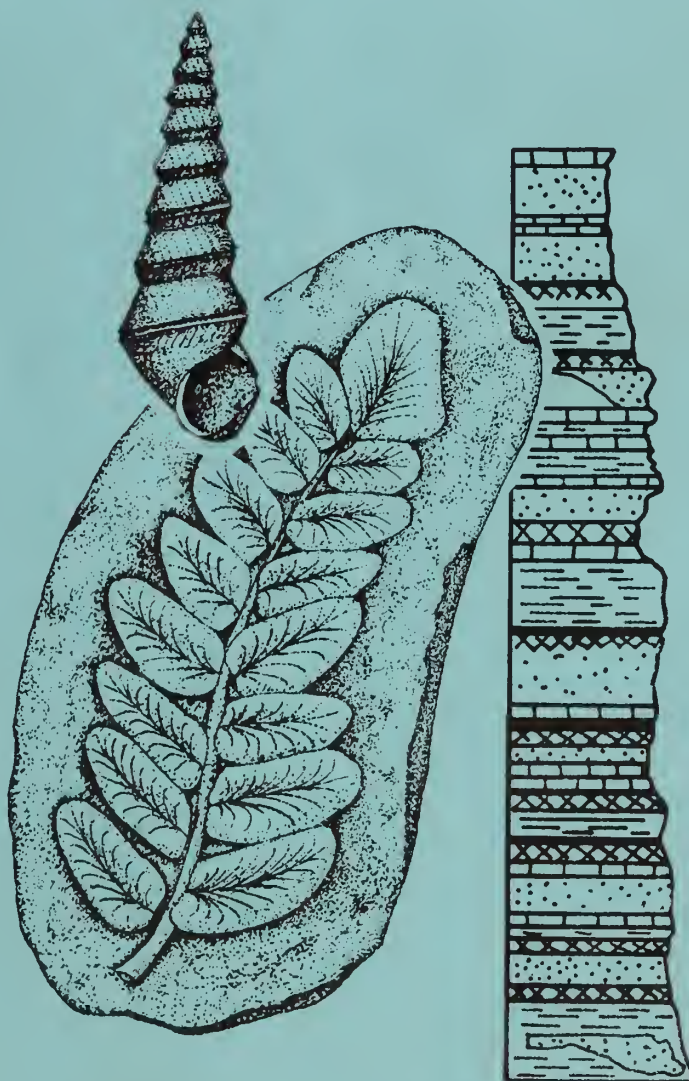
Illinois State Geological Survey

R. G. Johnson

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University of Chicago

supplemented by related papers



Illinois State Geological Survey Guidebook Series No. 8

Urbana, Illinois 61801

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GUIDEBOOK SERIES 8
ILLINOIS STATE GEOLOGICAL SURVEY

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DEPOSITIONAL ENVIRONMENTS IN PARTS OF THE CARBONDALE FORMATION- WESTERN AND NORTHERN ILLINOIS

Francis Creek Shale and Associated Strata and Mazon Creek Biota

INTRODUCTION

This field guidebook and contributed papers emphasize the stratigraphy and environments of deposition of rocks in the lower part of the Carbondale Formation in Illinois. The field trip committee hopes that the arrangement of the route, together with the background information included in the papers, will provide an opportunity to gain insight into some of the geological processes responsible for the widespread distribution of Pennsylvanian coals and their associated strata, as well as irregularities in the sequence.

The first day will be spent in western Illinois examining exposures of coals of the Carbondale Formation together with the overlying shales and thin marine units, many of which exhibit characteristic faunas and other features persistent over wide areas. Relationships between sulfur content and other characteristic features in the coal to the lithologic relationships in the overlying strata will be studied at 2 strip mines.

The second day will be spent in northern Illinois where the morning will be devoted to study of the sequence of lower and middle Carbondale strata on the west flank of the La Salle Anticlinal Belt. The afternoon will be devoted to study of the sedimentational features and excellently preserved fauna and flora of the Francis Creek Shale Member, a clastic wedge in the sequence overlying the Colchester (No. 2) Coal, in strip mines near Wilmington in northeastern Illinois.

Northwestern Illinois has long been a classic area for students of Pennsylvanian stratigraphy. The concept of a cycle of sedimentation was first conceived in this area by Udden (1912), who, in describing the geology of the Peoria Quadrangle, first noted the repetitive sequence including coals, marine limestones, shales, and sandstones. Weller (1930) noted the widespread extent of cyclic sedimentation, and the term cyclothem was subsequently introduced by Wanless and Weller (1932) to describe the cyclic sequence. It was also in this area that Wanless (1929, 1931, 1957) became acquainted with the Pennsylvanian. Wanless later was to become a leading authority on Pennsylvanian stratigraphy in North America.

The Pennsylvanian System in the Illinois Basin is characterized by rapid and sharp vertical changes in rock types and by lateral persistence of many of the units, especially limestones, certain shale types, coals, and seatrocks. The detrital rocks, sandstones, siltstones, and most of the shale types, however, show much variation horizontally, but as composite units, they too, are persistent over wide areas.

The area west of the Illinois River lies structurally on the northwestern flank of the Illinois Basin in a stable tectonic area referred to as the Western Illinois Shelf. Pennsylvanian rocks are thin, ranging from 0 to 500 feet thick and consisting of the following formations in ascending order (fig. 1): Abbott (50 feet), Spoon (75 feet), Carbondale (250 feet), and Modesto (125+ feet). The Bond

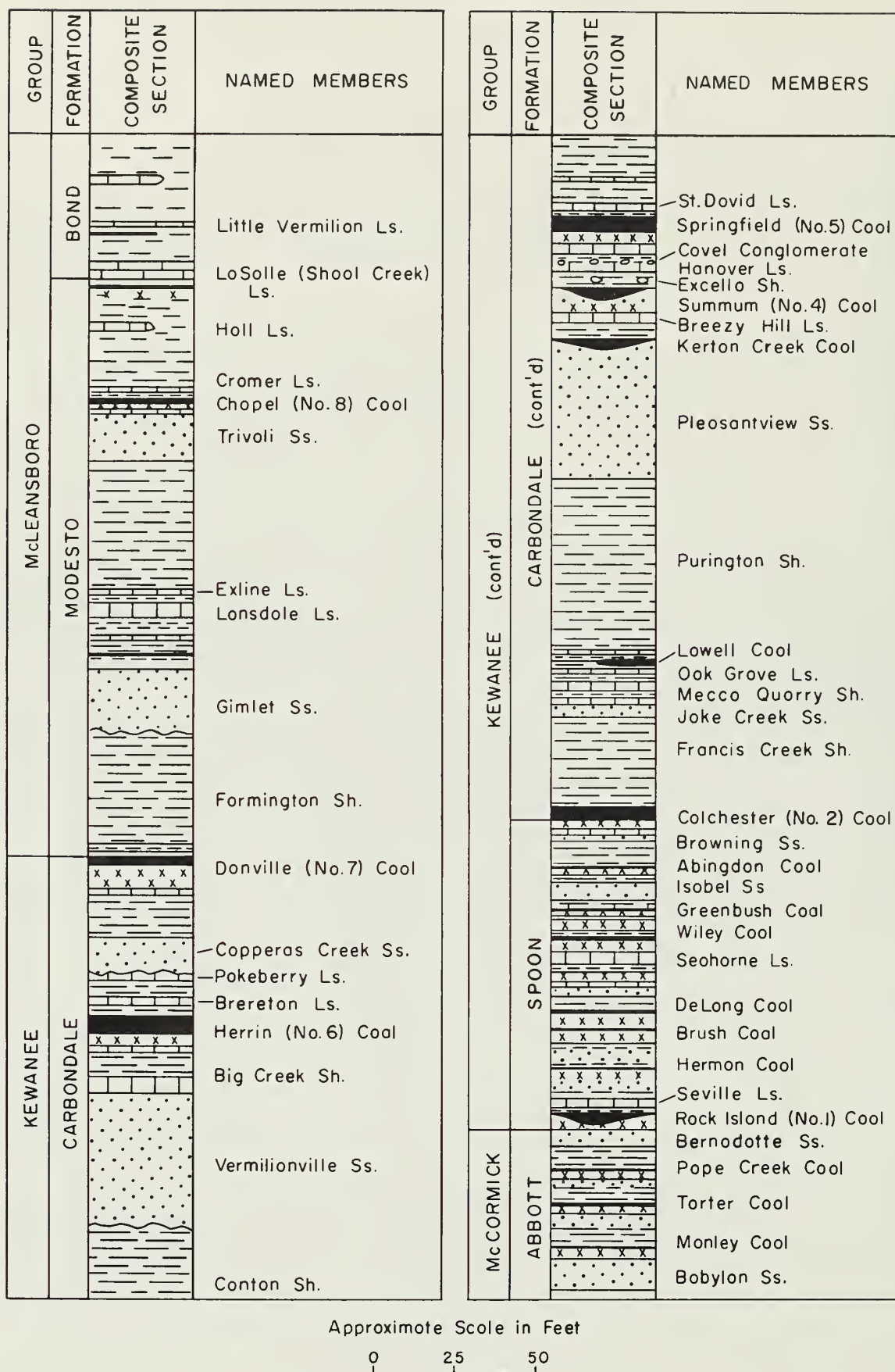


Fig. 1 - Generalized columnar section of Pennsylvanian strata in northern and western Illinois, modified from Smith, 1963, following Wanless, 1957.

and Mattoon Formations, the uppermost formations of the Pennsylvanian, are not preserved in western Illinois. The Bond Formation occurs above the Modesto and is present in northern Illinois in the area to be visited on the second day of the trip. The highest Pennsylvanian (Mattoon Formation) occurs in the area of the deeper part of the Illinois Basin in central and southern Illinois. The Caseyville Formation (the oldest Pennsylvanian in the state) is confined to a small area near Rock Island.


Sedimentation during Pennsylvanian time was greatly influenced by structure. The most pronounced structural feature of Illinois, besides the sedimentary basin, is the La Salle Anticlinal Belt, which had its inception prior to the beginning of Pennsylvanian sedimentation and was active during and after Pennsylvanian time. This structure and other major structural features of Illinois are briefly described by Clegg (this Guidebook, p. 106). A comprehensive study of the Pennsylvanian geology of the La Salle area, to be visited on the second day of the trip, is found in Willman and Payne (1942).

The rocks in the Carbondale Formation of northern and western Illinois are of considerable economic importance. Coal is one of the most important mineral resources in western Illinois, where limestone, clay, and shale are also mined. In northern Illinois, coal is not mined as extensively as it once was; however, limestone, clay, and shale are of considerable importance. Western Illinois has for many years been one of the chief coal-producing regions of the state, strip mining being of major importance. Regional dips are less than 20 feet per mile, and when coupled with the flat topographic surface, large areas of coal occur under constant overburden thickness. The principal coals which have been mined are the Rock Island (No. 1), Colchester (No. 2), Springfield (No. 5), and the Herrin (No. 6). The last three, all members of the Carbondale Formation, are the most important. The Rock Island (No. 1) Coal is a member of the Spoon Formation. Limestone, mined for agricultural purposes, for concrete aggregate and road stone, and for the manufacture of cement, is produced from 3 Pennsylvanian units: The Seville Limestone Member (Spoon Formation), the Lonsdale Member (Modesto Formation), and most importantly, the La Salle (Shoal Creek) Limestone Member, which occurs at the base of the Bond Formation. Clay and shale from the Pennsylvanian are produced from the Cheltenham Clay Member (Spoon Formation), which is well developed below the claystone seat-rock of the Colchester (No. 2) Coal in the vicinity of and to the east of the La Salle Anticlinal Belt, from the Francis Creek Shale and Purington Shale Members of the Carbondale Formation, and from the Farmington Shale Member of the Modesto Formation.

This Guidebook emphasizes the lower part of the Carbondale Formation, in the rocks which lie closely above, and immediately below, the Colchester (No. 2) Coal. The character and depositional environments of the lenticular Francis Creek Shale are discussed by Smith (p. 34) and Shabica (p. 43), the flora of No. 2 Coal and the Francis Creek Shale by Peppers and Pfefferkorn (p. 61), and the Francis Creek fauna by Johnson and Richardson (p. 53). Some petrographic aspects of the No. 2 Coal are discussed by Damberger (p. 99) and the relation of sulfur in the coal to stratigraphic relations of the overlying strata are discussed, in general, by Gluskoter and Hopkins (p. 89), and in the No. 2 Coal, in particular, by Hopkins and Nance (p. 96). Aspects of clay mineralogy of the No. 2 Coal and associated strata are discussed by Hughes (p. 84). Petrography of the limestones observed on the trip are presented and illustrated by Nance (p. 75). Clastic dikes, unusual features abundant in the Springfield (No. 5) and Herrin (No. 6) Coal Members in western Illinois, are discussed by Damberger (p. 111).

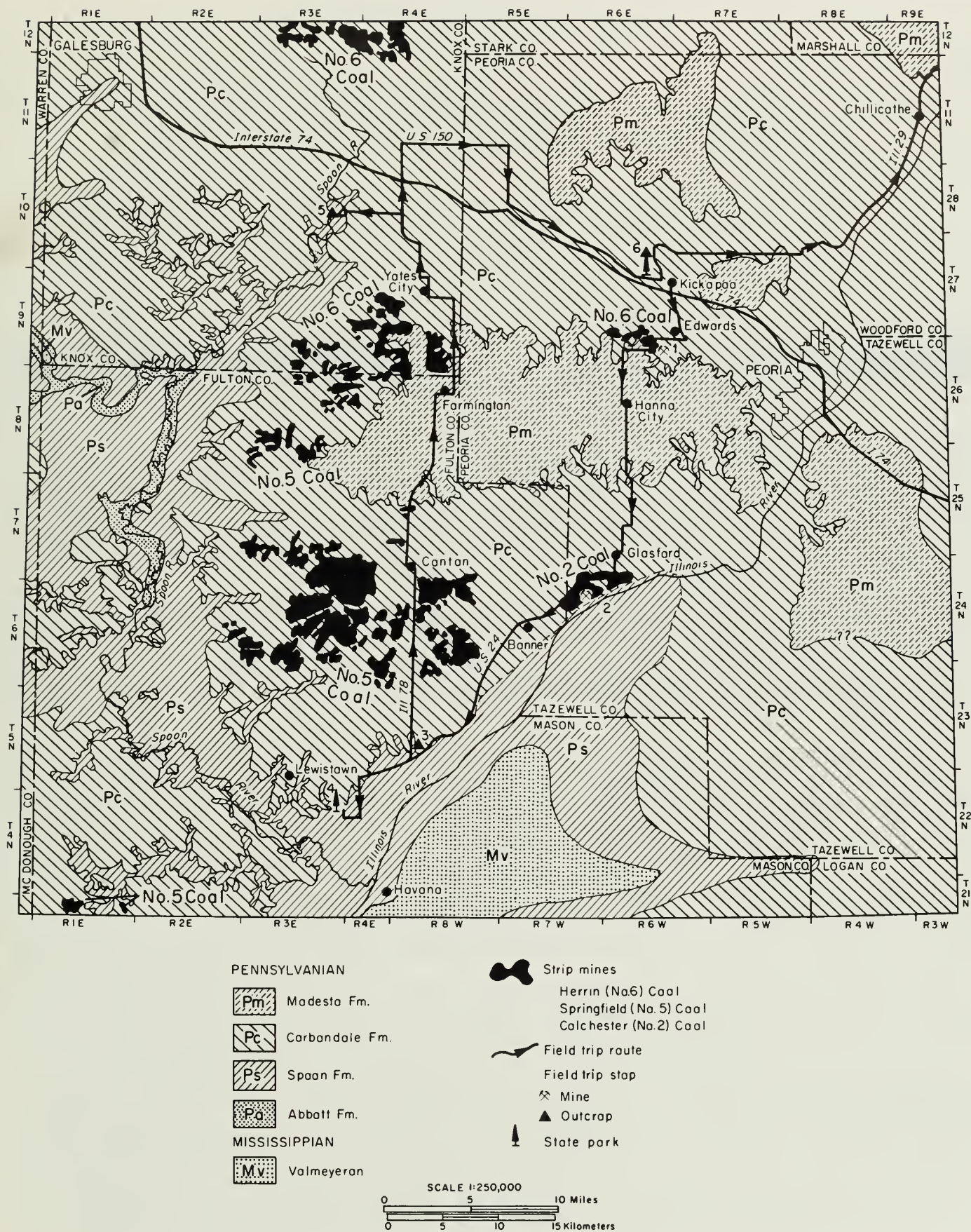
ACKNOWLEDGMENTS

We are grateful for the assistance provided by the Analytical Chemistry Section of the Survey for the various coal analyses, to the Chemical Engineering Section for the float-sink analyses of the coal, and to the Stratigraphy Section for their fossil illustrations, including the cover. H. B. Willman provided the information on the Pleistocene events included in the Road Log. Field notes by the late H. R. Wanless were extensively used in preparing for this trip. The personnel at the Peabody Coal Company Edwards and Northern Illinois Mines, and the United Electric Coal Companies, Banner Mine were most cooperative and we extend particular thanks to officials of these companies for their assistance.



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First day - Geology and route map, western Illinois, modified after Geologic Map of Illinois, 1967.

PEORIA TO STARVED ROCK STATE PARK

MONDAY, NOVEMBER 9, 1970

Leaders: H. H. Damberger, M. E. Hopkins, R. G. Johnson, R. B. Nance,
E. S. Richardson, Jr., C. W. Shabica, and W. H. Smith

- 0.0 Leave Père Marquette Hotel at corner of Main and Madison, travel south on Main for 2 blocks and turn left (east) on Adams St.
- 0.5 Take westbound entrance to Interstate 74 (towards Galesburg).
- 4.5 Junction U. S. 150 (War Memorial Dr.). Proceed straight on Interstate 74. Thick loess deposits on left and right for $\frac{1}{4}$ mile.

Mining in western Illinois has paralleled the development of stripping machinery, since the greatest portion of the total coal mined has come from stripping. Many of the large machines were developed in this field, and the first stripping wheel used in this country was built in Fulton County. For the last several years, Fulton County has ranked either first, second, or third among the many counties of Illinois producing coal, and in 1969, it ranked third, producing 6,131,000 tons. The Springfield (No. 5) and the Herrin (No. 6) Coals account for most of the production in western Illinois, although the Colchester (No. 2) and the Rock Island (No. 1) are also mined. No large underground mines are operating at this time in this part of the state. Ten strip mines were active during May, 1970, in Fulton, Peoria, Stark, and Knox counties.

- 11.7 Exit from interstate at Peoria County Rt. 18 (access road to U. S. 150). Turn left (south) towards Edwards on Rt. 18.
- 13.8 Turn right after going down hill, pass through the village of Edwards and cross railroad tracks.
- 14.0 Turn right (west) on Ill. Rt. 8.
- 14.5 Cross Kickapoo Creek.
- 15.2 Turn left (south) on blacktop road at junction with entrance to Edwards Mine.
- 15.6 Cross Cottonwood School Rd. and turn left, 0.1 mile ahead.
- 15.8 STOP NO. 1. PEABODY COAL COMPANY, EDWARDS MINE.

Typical features of the sequence between the Herrin (No. 6) and Danville (No. 7) Coal Members, Carbondale Formation in western Illinois that can be studied in the Edwards Mine, Peoria County, Section 25, T. 9N., R. 6E. of 4th Principal Meridian are described below:

The "white top" disturbance (light gray, silty claystone with coal fragments, developed on the coal and filling associated cracks in the coal) is prominently displayed at this locality (Damberger, this Guidebook, p. 115). Under the sandstone-filled channel (fig. 2), the cracks in the coal are filled with sandstone rather than with the usual light gray claystone. The deeper and larger cracks, however, often contain claystone in their lower portion, which seems to indicate that they were originally filled with clay that was subsequently removed and replaced by sand. There is remarkably little differential compaction between the coal and the sandstone of dike filling, as indicated by the generally small contortion of sandstone-filled cracks in the coal.

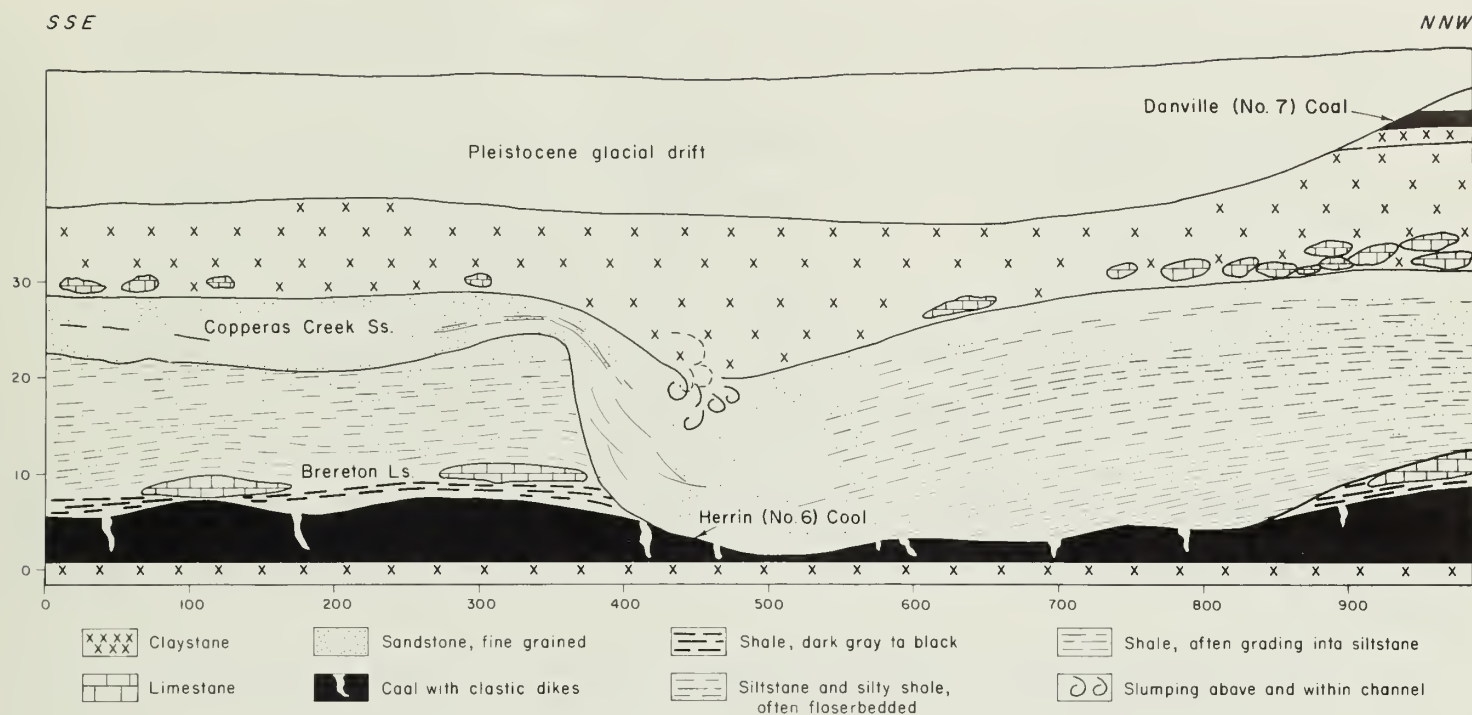


Fig. 2 - Stop 1. Sketch of highwall at Peabody Coal Company, Edwards Mine at Incline No. 1.

A sandstone-filled channel has been present in the central part of the active mine for several years. Its size and appearance vary greatly with highwall advancement. Figure 2 shows its shape in late 1969. Toward the south-southeast, the channel sandstone is connected to a sandstone of uniform thickness (Copperas Creek Sandstone Member). Toward the north-northwest, the channel sandstone grades into a sandy, silty shale with many sandstone lenses. Generally, this unit becomes more sandy upward. Flaser-bedding, which is typical in the upper part of the unit, can also be observed within the channel proper.

The channel was cut into a sequence of sandstones, siltstones, and shales similar to those into which the channel sandstone grades toward the north-northwest. Flaser-bedding is common in the upper, more sandy portion of this sequence, where burrows are also characteristic. The claystone above the channel slumped down the slope above the channel sandstone. The top layers of the channel sandstone were contorted, and the overlying claystone was dragged down into the channel, enveloping chunks of sandstone (fig. 2).

The claystone series above the Copperas Creek Sandstone and below the Danville (No. 7) Coal has, in part, been heavily jumbled by penecontemporaneous slumping. Lense-shaped bodies 1 foot or more thick, which are surrounded by polished slickensided planes, can be observed in the lower portion of the claystones.

The Brereton Limestone Member occurs in lenses which vary in length (from a few feet to hundreds of feet) and thickness (0 to 6 feet) along the highwall. Generally a thin, black, hard "slaty" shale underlies the limestone. This relation can best be studied in the "dragline incline" in the southern part of the mine.

Cracks up to about 4 inches wide have been observed in the Brereton Limestone. They are filled by a breccia composed of shale and limestone fragments in a fine grained matrix. In no case could a connection to cracks in the underlying coal be established. However, 1 crack has been observed in the limestone directly above a large clay-filled crack in the coal underneath. A layer of uninterrupted shale was found to separate the 2 cracks.

The black shale also contains many fine fissures filled with light gray claystone similar to that which is found in the coal. The shale-siltstone-sandstone series above the Brereton Limestone and below the Copperas Creek Sandstone exhibits many irregular cracks, about $\frac{1}{2}$ to 2 inches wide, which

contain shaly ironstone concretions. Although most of the cracks are nearly vertical, some are inclined.

15.8 Retrace route back to junction with Cottonwood School Rd.

16.0 Turn left on Cottonwood School Rd. (gravel) and proceed through mined-out area.

16.4 Cross haulage road.

17.4 Leave stripped area and pass through Cottonwood School district.

18.0 Turn left (south) at junction with Peoria Co. Rt. 78 (McAlister Rd.).

From here to Glasford the route is on the loess-mantled Illinoian till plain, which is an exceptionally flat surface. The plain is the result of stagnation of the glacier, which is downward melting of the ice when forward motion ceases. In places, the highway crosses valleys sharply entrenched in the till plain, which have resulted from headward erosion of streams tributary to the Illinois River.

20.4 Note exposure on right of rocks of the Gimlet Cyclothem, including the Lonsdale Limestone (fig. 1).

20.8 Turn left (east) at junction with Rt. 116 (Farmington Rd.), enter Hanna City.

20.9 Turn right (south) at junction with Glasford Rd.

23.0 Enter Smithville.

23.2 Junction Smithville Rd., proceed straight ahead.

26.6 Cross tributary to Copperas Creek.

28.6 Pass gas storage area.

In this area, natural gas is stored in the circular Glasford Dome in the Silurian Niagaran Dolomite at a depth of 800 feet. The maximum volume in storage (1968) was 4,500 MMcf, involving a total of 3200 acres. A total of 11 operating and 12 observation wells are involved.

The Glasford Dome has been described by T. C. Buschbach as having formed by gradual upward growth over the site of a 400 million-year-old meteorite impact crater. This has resulted in 100 feet of closure on the Colchester (No. 2) Coal (fig. 3). The impact probably took place in very early Cincinnati time, resulting in a zone of intensely brecciated rocks of pre-Maquoketa age (fig. 3) more than 2 miles in diameter and at least 1,500 feet thick (Buschbach and Ryan, 1963). The development of the uniquely domed structure is interpreted by Buschbach and Ryan (1963):

"Every recognizable stratigraphic unit above the basal Maquoketa thins over the top of the dome. Isopach maps of the overlying formations resemble those showing thinning of beds over reefs and buried hills, and it seems probable that the thinning is due chiefly to the presence of a relatively non-compactable core of breccia. There is also a possibility that there has been gradual relative uplift of the central brecciated zone, either by continuing rebound after impact or by deep-seated regional forces producing an upward movement through the weakened area of disturbed rocks. The structure in the Maquoketa and younger rocks developed slowly, apparently never exceeding $1\frac{1}{2}$ feet and averaging only $\frac{1}{2}$ foot per million years."

29.0 Cross County Rd. No. 78 (Scott Rd.).

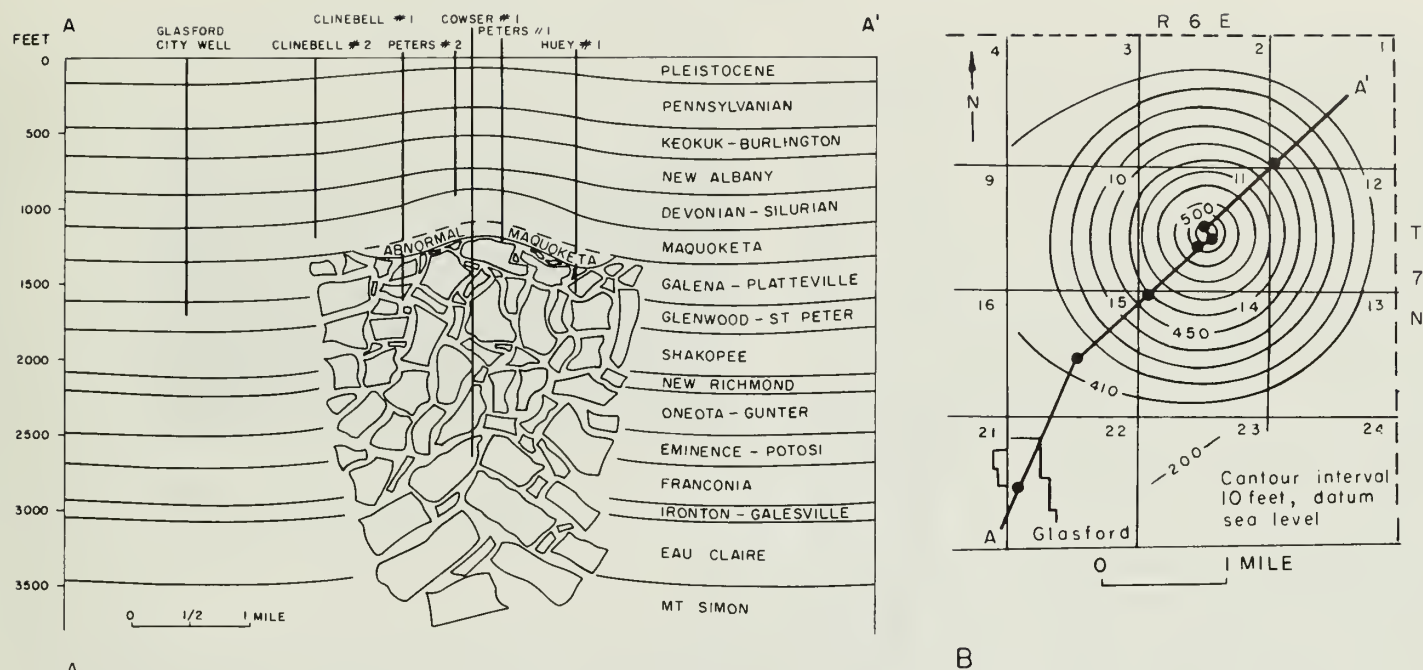


Fig. 3 - (A) Interpretative cross section through the Glasford Gas Storage Structure, after Buschbach and Ryan (1963), and (B) structure of the Glasford dome shown by structure contours on top of Colchester (No. 2) Coal compiled by George H. Otto (location of wells used in constructing section A-A' added).

29.5 Bear right and enter Glasford (Main St.).

30.0 Turn left (south) on S. Lancaster St. (St. Hwy. No. 175).

Leaving Glasford, one can see ahead the Illinois Valley, about 200 feet lower. The valley is about 20 miles wide southeast from here, and it is eroded in a broad fill of glacial drift in the Ancient Mississippi Valley. The Mississippi River, which occupied this valley through most of the Pleistocene, was not diverted to its present position westward from Rock Island until the Wisconsin glacier reached the Big Bend of Illinois River, 50 miles north of here, about 20,000 radiocarbon years ago.

The bedrock valley is about 400 feet deep. It is largely filled with drift deposited by the Kansan and Illinoian glaciers and outwash from the Wisconsin glaciers that reached Peoria, about 10 miles to the east. The Illinois River is entrenched in the glacial deposits, except in a few areas where widening of the valley by rivers from the Wisconsin glaciers has cut a bench into the bedrock bluffs. This accounts for the shallow overburden on the bedrock at the next stop. Descending the bluffs, the highway cuts through 30 to 40 feet of loess that was blown from the glacial outwash in the valley.

31.7 Turn right (west) at junction with U. S. Rt. 24.

31.9 Stripped area of Banner Mine on left where Colchester (No. 2) Coal of Carbondale Formation is being mined.

33.1 Turn left (southeast) at Banner Mine entrance and follow haulage road.

34.1 Turn left.

34.2 STOP 2. UNITED ELECTRIC COAL COMPANIES, BANNER MINE.

In this vicinity the Colchester (No. 2) Coal Member (Carbondale Formation) lies very near the surface of the Illinois River floodplain with a slight local dip to the northwest. The coal has an average overburden thickness of about 20 to 30 feet, (mostly shale), making excellent strip mining conditions. United Electric Coal Companies Mine No. 27 (Banner Mine) has been in operation for 11 years and has produced 686 thousand tons during 1969 from an average coal thickness of 30 inches (Damberger, this Guidebook, p. 99). A petrographic description of the coal and description of coal balls from this mine is given by Damberger (this Guidebook, p. 99).



Fig. 4 - Stop No. 2 (Banner Mine). Shows undulating upper surface of the Colchester (No. 2) Coal Member.

The coal forms large swales (or rolls) with a vertical relief up to 20 feet (figs. 4 and 5), which have a lateral extent of several hundred feet along the highwall. The Francis Creek Shale Member is often confined to these swales. It has a maximum observed thickness of 13 feet and contains a marginal marine fauna (faunal list, p. 50). The deposits of Francis Creek Shale have been observed to be elongate in a general east-west direction (approximately 45° to the highwall). Sulfur variations related to this gray shale are discussed by Hopkins and Nance (this Guidebook, p. 97).

The No. 2 Coal and/or Francis Creek Shale is overlain by the Mecca Quarry Shale Member, which is a black, sheety shale with many small phosphatic lenses, which produce a pimply structure. The shale is generally about 2 feet thick, but may be thinner on the higher areas between the swales (fig. 5). In this case, it is overlain by thick (up to 5 feet) deposits of the lowermost limestone unit of the Oak Grove Limestone Member, which is crinoidal throughout and contains phylloid algae in the upper part (figs. 6, 7, and 8). The overlying portion of the Oak Grove Limestone is represented by dark gray shale, the lower part of which contains sideritic bands up to 2 inches thick. The upper part of this shale is partly zoned by fossils, containing Mesolobus mesolobus (plate 1) and Marginifera muricatina (plate 1) near the base and pectinoid pelecypods near the top. Two prominent, but thin, limestones may be exposed near the top of the highwall. The lower limestone contains abundant Linoproductus cora (plate 1), while the overlying unit has many small gastropods and fragments of other fossils, all mainly preserved as casts. These upper units of the Oak Grove Limestone Member are overlain by the Purington Shale Member (fig. 5), which is a light to medium gray uniform shale.

34.2 Retrace route back to junction with Rt. 24.

35.3 Turn left (southwest) on Rt. 24.

38.1 Banner corporate limit, follow U. S. 24.

45.9 Pleasantview Sandstone Member of Carbondale Formation exposed along bluff on right. Small abandoned mines above, operated in the Springfield (No. 5) Coal Member.

47.5 STOP NO. 3. MAPLES MILL SECTION.

Most of the members of the Summum and St. David Cyclothems (Carbondale Formation) can be observed at this road cut, although the section is no longer well exposed. Sandy algal (?) nodules (up to 6 inches in diameter), representing the Breezy Hill Limestone Member (Nance, this Guidebook, p. 76), are present near the base of the claystone below the Summum (No. 4) Coal Member at the south end of this exposure. The basal member (Pleasantview Sandstone) of the Summum Cyclothem

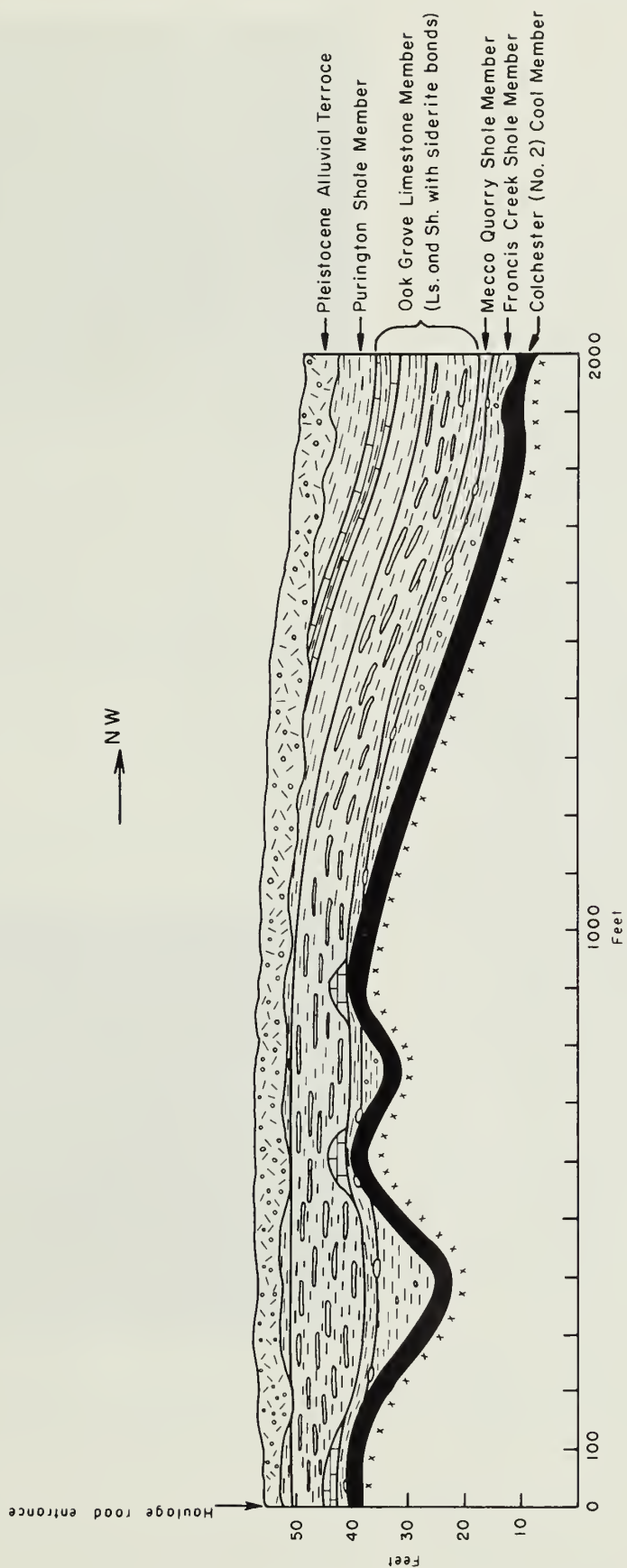


Fig. 5 - Stop No. 2. Exposure highwall at United Electric Coal Companies, Banner Mine, SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 12, T. 6N., R. 5E., Fulton County.

is not present here, although its sheet sandstone phase is exposed within a quarter of a mile east and west along the Illinois River bluffs. Apparently, the Breezy Hill Limestone directly overlies the Purington Shale (uppermost member of the Liverpool Cyclothem), the lower portion of which was present at Stop No. 2 (Banner Mine). The Summum (No. 4) Coal is represented by about 8 inches of dark gray to black shale with vitrain streaks. The No. 4 Coal horizon is overlain by a thin (1- to 2-inch thick) carbonate bed consisting of fine, sand size phosphatic grains cemented by coarsely crystalline calcite (Nance, this Guidebook, p. 76) and contains phosphatic wood fragments. The Excello Shale Member (fig. 9) overlies the phosphatic bed and contains large dark gray spheroidal limestone concretions up to 6 inches thick in the lower part. These concretions were not observed to be fossiliferous at this locality, although they contain abundant cephalopods elsewhere. Dark gray, fissile shale overlies the Excello and is the uppermost unit of the Summum Cyclothem in western Illinois. The marine section, which includes the Covell Conglomerate and Hanover Limestone Members, normally present below this shale is absent here (Stop No. 6, fig. 12).

The St. David Cyclothem has no basal sandstone member in western Illinois (Wanless, 1957) so that the claystone below the Springfield (No. 5) Coal Member is in sharp contact with the dark gray shale of the Summum Cyclothem. Discontinuous bands and nodules of light gray, lithographic limestone occur in the lower portion of this claystone. These limestones appear to be brecciated, possibly due to abundant calcite-filled syneresis cracks.

The No. 5 Coal is split by about 11 inches of claystone in the extreme lower part and has been partly mined out in a drift near the middle of the exposure and in a small strip mine north of the exposure along the west side of the road. The overlying marine sequence of the St. David Cyclothem is typical of a normal Illinois Pennsylvanian cyclothem. The black, "slaty" shale is well developed and contains spheroidal limestone concretions at the base. The black shale grades upward into a dark gray shale, which has an abrupt contact with the St. David Limestone Member (fig. 8). This limestone, the underlying black shale, and limestone concretions have a diverse fauna, (with brachiopods predominating), are very widespread, and are uniform in appearance throughout the area



Fig. 6 - Stop No. 2 (Banner Mine). Limestone lens located on the crest of one of the large rolls shown in fig. 4. This is the lowermost limestone unit of the Oak Grove Limestone Member developed over a thin interval of the Mecca Quarry Shale Member. A 6-inch micrite band is shown above the hammer head.



Fig. 7 - Stop No. 2 (Banner Mine). Lower surface of the limestone shown in figure 6, showing abundant, large burrows.

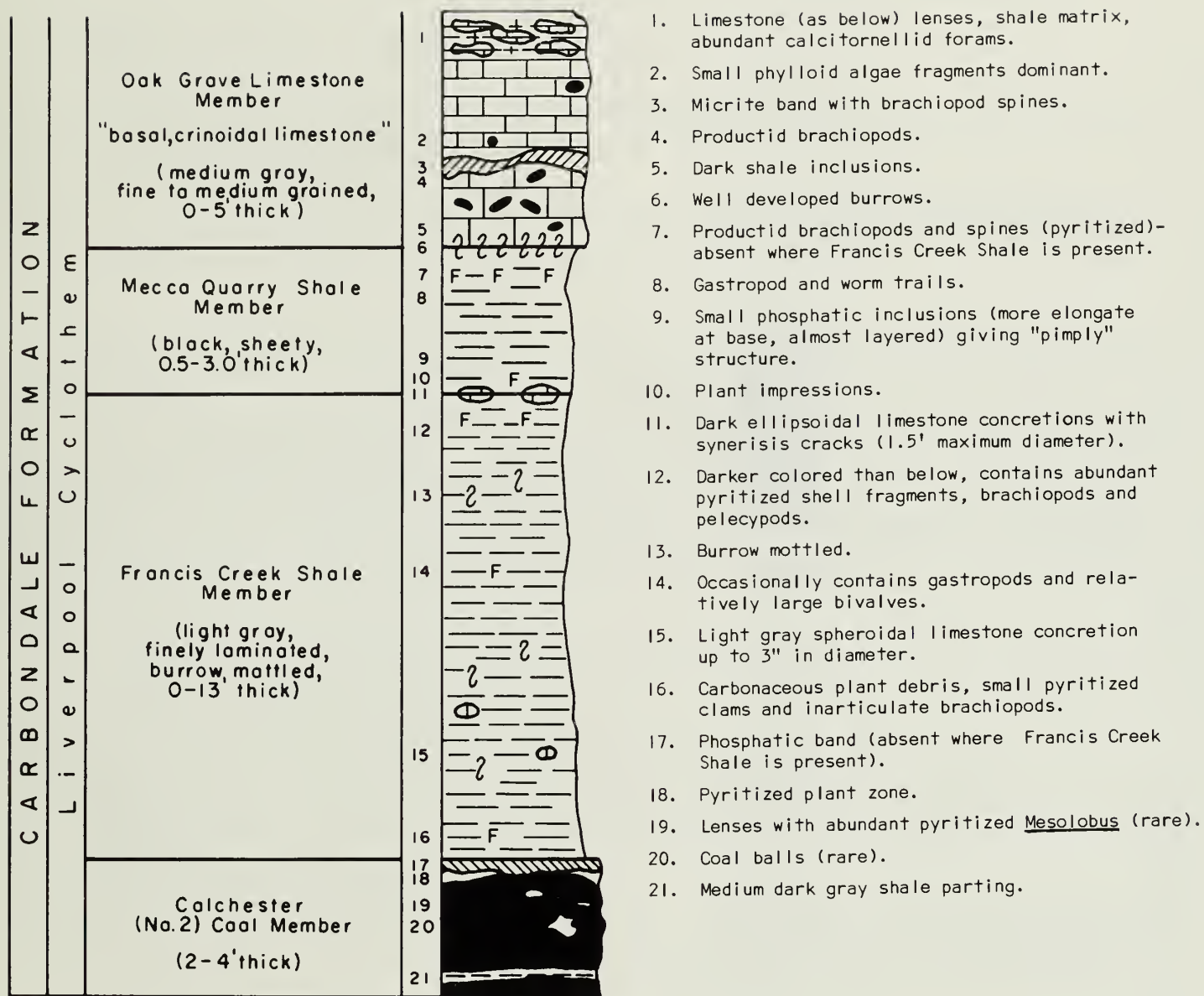
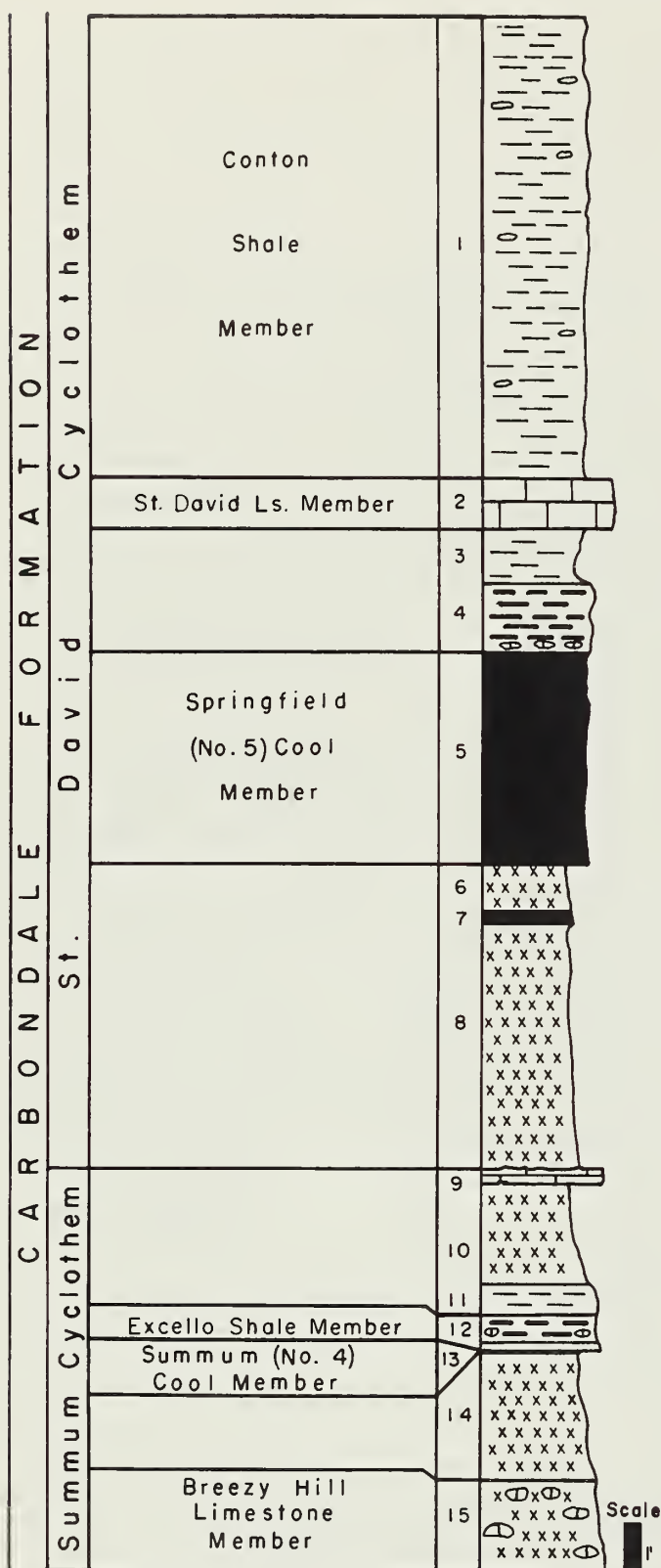


Fig. 8 - Stop 2. Generalized section of the lowermost units at the Banner Mine.



1. Shale - medium gray, weathers light brown, fairly well laminated, contains many siderite nodules, becomes slightly darker downward.
2. Limestone - medium gray to medium dark gray, weathers light tan, argillaceous, finely crystalline, fossiliferous: brachiopods, pelecypods, gastropods.
3. Shale - dark gray to black; fissile.
4. Shale - black, "slaty," lower portion contains larger spheroidal pyritic carbonate concretions.
5. Coal - has been mined out under the hill.
6. Claystone (seatrock) - medium gray to medium dark gray, carbonaceous plant fragments.
7. Coal - top 3" bony, lower 1½" bright and blocky, ¼" dark gray shale parting.
8. Claystone - medium gray, hackly fracture, approaches a shale.
9. Limestone - light gray to medium gray, nodular, micritic.
10. Claystone - light gray to medium gray.
11. Shale - dark gray.
12. Shale - black, "slaty," thin phosphate lenses, large medium dark gray dolomite concretion at base. Phosphate band - medium-grained, sparry, calcite cement, partially phosphatized wood fragments.
13. Coaly shale - mottled with pyrite on bedding planes, thin vitrain lenses.
14. Claystone - medium gray with ¼" limestone "pellets."
15. Claystone - medium gray with algal nodules 4 to 6" in diameter. 2" thick.

Fig. 9 - Columnar section, just north of U. S. 24 along west side of road to Maples Mill. SE¼, NE¼, Sec. 14, T. 5N., R. 4E., Fulton County, Havana Quadrangle.

(Wanless, 1957). The overlying Canton Shale Member contains small ironstone concretions throughout, which most often characterize the uppermost shale member of a cyclothem. It is somewhat fossiliferous near the base at several localities in western Illinois (Wanless, 1957).

47.5 Continue southwest on U. S. 24.

50.9 Junction with State Rt. 78 at Little America, continue southwest on Rts. 24 and 78.

53.0 Turn left (south) on Rt. 78 and 97 at junction with Rts. 24 and 97.

54.5 Descend Illinois River bluff onto wide floodplain. Large cattle feeding station at base of bluff. A large floodplain lake, which has been artificially drained, formerly occupied this part of the valley.

56.6 Turn right (west) across small bridge over canal at sign to Dickson Mounds State Park.

58.3 STOP NO. 4. DICKSON MOUNDS STATE PARK. LUNCH.

Dickson Mounds State Park, located near the mouth of the historic Spoon River, contains a unique burial mound with over 200 undisturbed graves, now carefully exposed and covered over by the museum building. The burials are in their original positions in the Peoria Loess, and bone structures are essentially undecayed, probably because of the abundant calcareous material in the loess. When burying the dead, the Indians did not dig a grave, but placed the body on the ground and covered it with the loess, thus, not disturbing previous burials. From this excellent preservation, specialists are able to diagnose many bone diseases and dental disorders. Other excavations have revealed buildings, animal bones, foodstuffs, pottery, and weapons. Radiocarbon dates indicate habitation of buildings just south of the mound at 1020-770 BP. The burials in the mound are younger; radiocarbon dating places them 770 to 570 BP. In this area the Peoria Loess is 25 to 35 feet thick and mantles the glacial drift and bedrock.

58.3 Leave park entrance and return to Rts. 78 and 97, turn left and retrace route to junction of Rts. 24 and 97 at Little America.

66.9 Turn left (north) onto 78 at Little America, junction of Rts. 24 and 78.

70.3 Strip mines - the Springfield (No. 5) Coal has been extensively stripped in the Canton-Cuba region. From here to the next stop the route is entirely on the flat, loess covered Illinoian till plain.

73.7 Continue north through village of Dunfermline.

74.4 Cross Rt. 100. Note United Electric Coal Companies, Buckhart Strip Mine on right for several miles. Observe land reclamation.

77.2 Enter Canton, continue through town on Rt. 78.

80.8 Truax-Traer Coal Company, Norris Strip Mine on left where both Springfield (No. 5) and Herrin (No. 6) Coals are mined.

82.9 Mine entrance on left.

84.3 Enter Farmington, follow Rt. 78 through town.

85.9 Bear left (north) on Rt. 78.

88.6 Reclaimed spoil banks on left (No. 5 Coal).

90.3 Cross Kickapoo Creek.

91.4 Turn left (west) on Rt. 8 at junction of Rt. 78 and Rt. 8.

92.4 Enter Yates City.

92.7 Turn right (north) on Main Street at Standard Oil Station, follow Knox County Rd. No. 18 north and be alert for numerous sharp turns.

98.4 Elba Center, continue ahead for 1 mile.

99.4 Turn left (west) onto gravel road, continue west for 3 miles.

102.4 Turn left (south), 1000 feet ahead bear right (west) on gravel road to Wolf Bridge.

103.0 STOP NO. 5. WOLF BRIDGE SECTION.

The Francis Creek Shale, Mecca Quarry Shale, Oak Grove Limestone Members, and the lower part of the Purington Shale Member are exposed at this locality just north of the bridge (figs. 10 and 11). The upper part of the Francis Creek Shale is normally exposed just above water level, under the bridge. The maximum observed thickness of the Francis Creek Shale is about 5 feet. The shale is similar in lithology to that seen at Stop No. 2 (Banner Mine), containing a marginal marine fauna (mostly pyritized) that is prolific near the top where the shale is darker in color. The black, "slaty" Mecca Quarry Shale is well exposed along the entire section and forms a small ledge near the base. The black shale has the characteristic pimply structure, due to small phosphatic lenses characteristic of the Mecca Quarry Shale throughout western Illinois. Although the shale is not very fossiliferous here, a few pyritized pectinoid pelecypods may be found near the base.

The overlying Oak Grove Limestone Member consists of an interbedded sequence of thin marine shales and limestones. The several units of the Oak Grove Limestone are usually characterized by a distinctive faunal element and are fairly persistent throughout western Illinois.



Fig. 10 - Exposure of Oak Grove Limestone Member on Spoon River at Wolf Covered Bridge (top photo). The No. 2 Coal and Francis Creek Shale are exposed at low water beneath the bridge adjacent to the western approach (right side of bottom photo). The Purington Shale overlying the sequence of beds in the Oak Grove Limestone Member are exposed at the top of the exposure. (Photos by R. M. Brown, Knox County Historical Sites, Inc.)

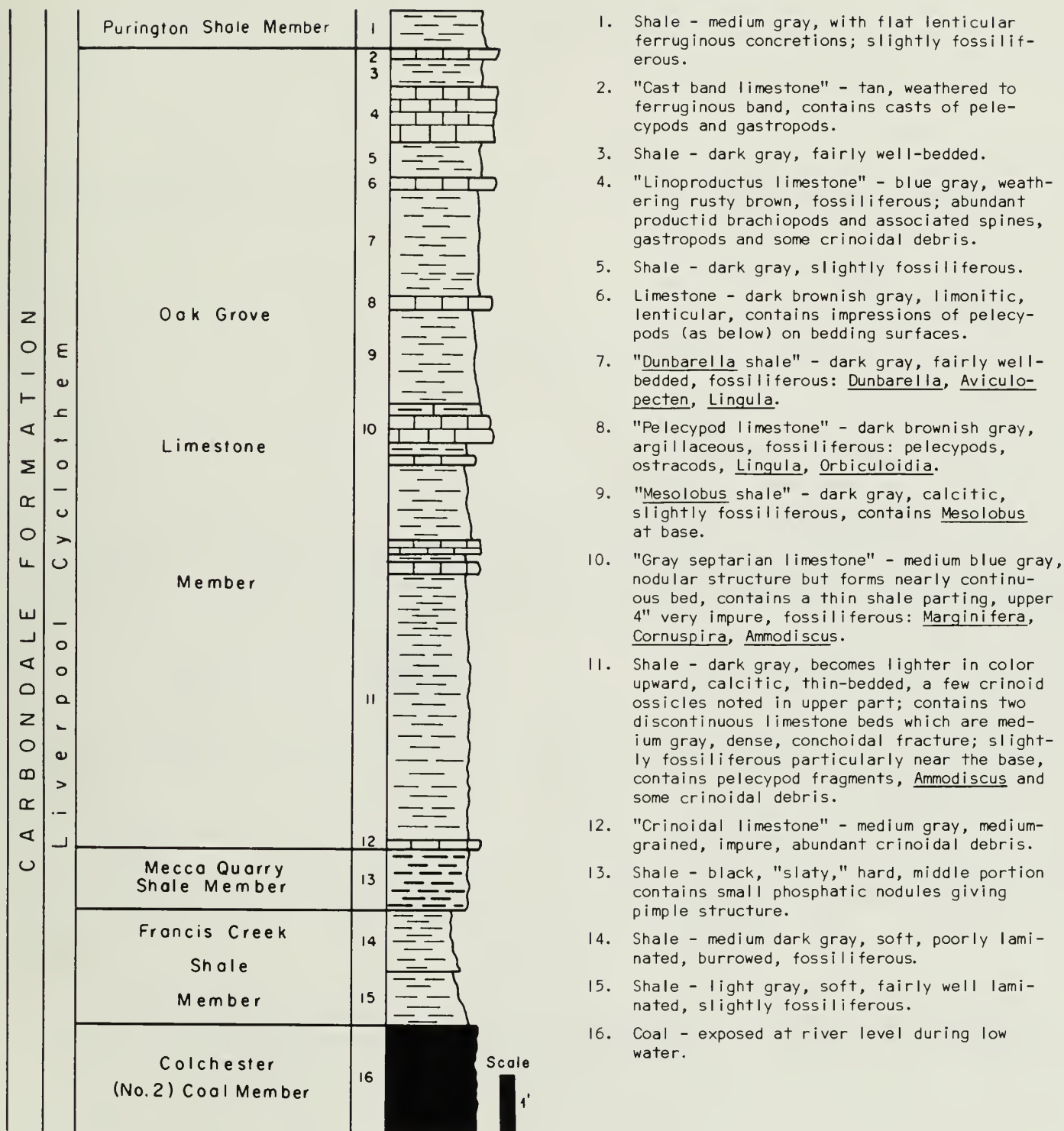


Fig. 11 - Columnar section, cutbank on Spoon River at Wolf Covered Bridge. NW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 13, T. 10N., R. 3E., Knox County, Maquon Quadrangle.

Several units have been recognized and correlated with formations in the Mid-Continent area (Wanless, 1957; Wright, 1965). Wanless (1931, 1957) has described 14 units of the Oak Grove Limestone Member and has informally named several of them. The Wolf Covered Bridge section is fairly representative of this sequence, with all the major units present (fig. 11). The Oak Grove Limestone Member is overlain by the medium gray Purington Shale Member which contains several horizons of laminated ironstone concretions.

103.0 Retrace route back to Knox County Rd. No. 18.

107.4 Turn left (north) on County Rd. No. 18, cross over Interstate 74 and continue north 3 miles to junction with U. S. 150.

110.4 Turn right (east) on Rt. 150.

111.9 Cross Rt. 180.

116.4 Junction Rt. 78 and 150, turn right (south) and continue on 150.

119.3 Cross Rt. 78.

119.6 Turn left (southeast) on U. S. 150.

121.6 Enter Brimfield, follow U. S. 150 through town.

A short distance ahead, the highway rises onto an Illinoian moraine, a relatively smooth-surfaced ridge about 40 feet high and 1 mile wide. It marks a stand of the Illinoian ice front after a significant readvance.

123.1 Cross junction with Oak Hill Rd.

127.3 Cross Kickapoo Creek.

129.3 Turn left (north) on Peoria County Rt. No. 5 toward Jubilee College State Park at junction with Princeville Rd.

130.8 Cross bridge over Kickapoo Creek.

131.2 Turn left (west) toward park entrance.

131.4 STOP NO. 6. JUBILEE COLLEGE SECTION.

The interval from the Sumnum (No. 4) Coal Member upward through the Springfield (No. 5) Coal Member is exposed at 2 localities in this area. The section is well exposed along a tributary to Kickapoo Creek that parallels the gravel road, which descends into Kickapoo Creek Valley from a point just west of the entrance to Jubilee College State Park. The Purington Shale Member is also exposed at this locality, and underlies, with a sharp contact, the underclay of the No. 4 Coal; the Pleasantview Sandstone and Breezy Hill Limestone Members are absent. About 100 yards upstream along Kickapoo Creek from where the gravel road fords the creek is a vertical section (fig. 12) that includes the black "slaty" shale over the No. 5 Coal and the overlying Canton Shale Member, which contains ironstone concretions. The intervening St. David Limestone Member is absent. The interval below the No. 5 Coal is poorly exposed and the section below the No. 4 Coal is completely covered.

The position of No. 4 Coal Member is represented by a thin, dark gray to black shale with vitrain streaks. The coal horizon is overlain by a thin (1- to 2-inch) spherulitic limestone

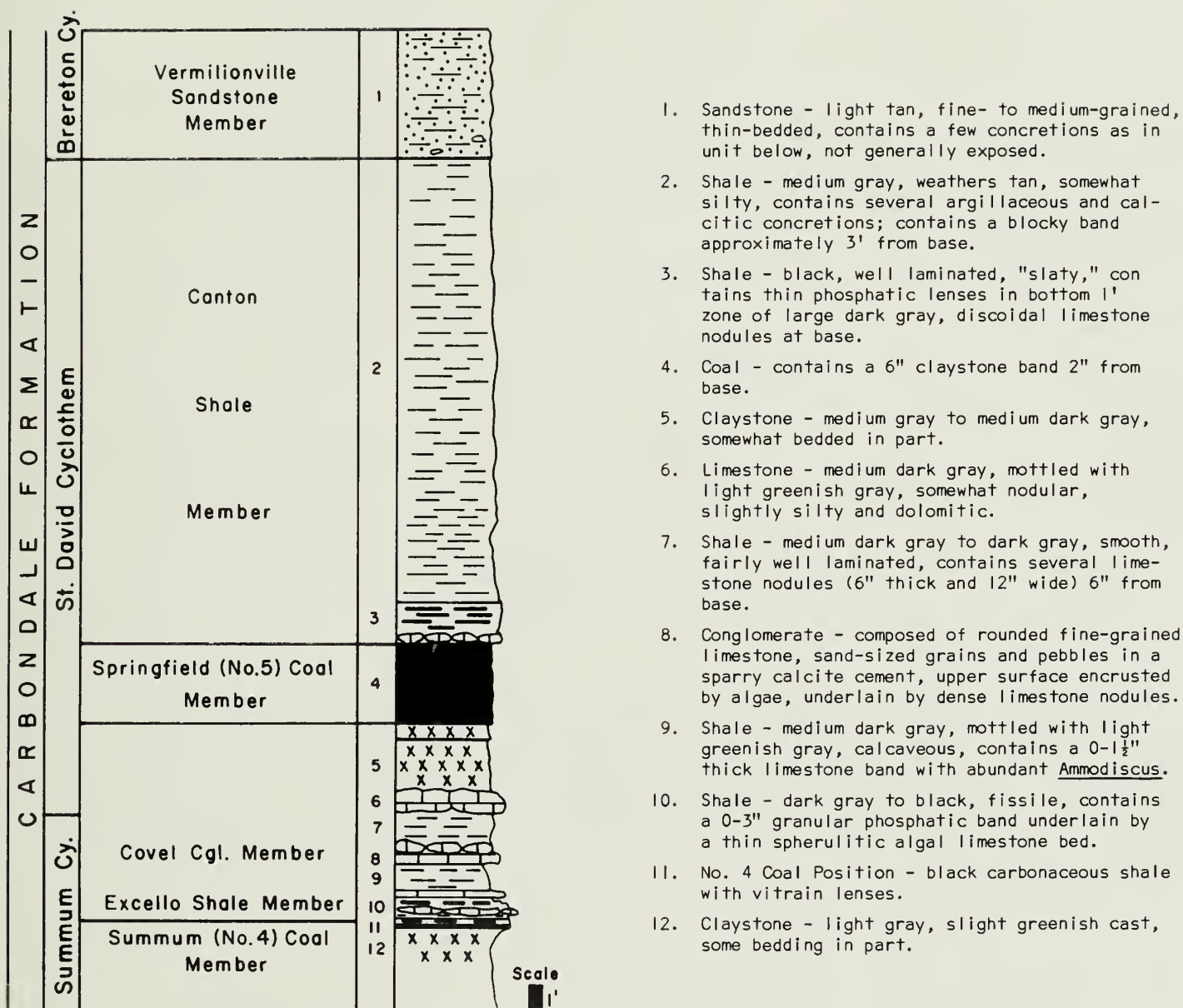


Fig. 12 - Columnar section in cutbank on Kickapoo Creek and in small tributary along road going west downhill from entrance to Jubilee College State Park. NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 26, T. 10N., R. 6E., Peoria County, Elmwood Quadrangle.

(Nance, this Guidebook, p. 76) which consists of medium to coarse grained, sand-size grains composed of radiating acicular calcite crystals (Nance, this Guidebook, plate 6, fig. 1) and is poorly cemented by sparry calcite. The spherules appear like small nodules (Nance, this Guidebook, plate 6, fig. 2) at the exposure along the tributary to Kickapoo Creek; the granular texture is enhanced by weathering. This unit is overlain by a thin (1- to 3-inch) bed composed of medium grained, sand-size phosphatic grains cemented by coarsely crystalline calcite. The unit contains phosphatic plant fragments and is similar to the phosphatic unit at Stop No. 3 (Maples Mill Section). Large (up to 1.5 feet in maximum diameter) ellipsoidal limestone concretions of the Excello Shale Member lie on top the phosphatic unit. The dark gray to black, soft Excello Shale is thin at this locality, and is present only where the limestone concretions are absent. The Excello Shale Member is overlain by a medium gray calcareous marine shale. The unit normally contains a $\frac{1}{2}$ inch limestone at the base, with abundant pelecypods and foraminifera (Ammodiscus). Several light gray limestone nodules can be observed near the top of this shale and may represent the position of the Hanover Limestone Member.

The Covell Conglomerate Member (Nance, this Guidebook, p. 77) overlies the medium gray calcareous shale and consists of light to dark gray, fine sand to pebble size, finely crystalline, rounded limestone grains which are cemented by coarsely crystalline sparry calcite. Although water-worn fragments of horn corals (Lophophyllidium), brachiopods, and pelecypods may be present in the conglomerate, none of the limestone grains were observed to contain invertebrate fossils, except for a few small calcitornellid foraminifera fragments. The upper surface of the conglomerate, or large grains near the upper surface, are encrusted by stromatolitic lamination (Nance, this Guidebook, p. 77 and plate 6, fig. 5). The Covell Conglomerate Member is overlain by a dark gray fissile shale with which the underclay limestone of the Springfield (No. 5) Coal is in sharp contact.

131.6 Exit park and turn left (north) on Peoria County Rd. No. 5 (Princeville Rd.).

131.8 Turn right (east) on Peoria County Rd. No. 21 (Grange Hall Rd.).

132.7 Cross bridge over Kickapoo Creek.

Shortly after crossing the valley of Kickapoo Creek, one can see ahead the prominent Bloomington Morainic system. The Bloomington Moraine is the front of the Wisconsin drift in this area. Its highest part, left (north) of the road, is about 150 feet above the Illinoian till plain. Because part of the Peoria Loess passes beneath the Wisconsin till, the loess is much thinner on the till than on the Illinoian till plain. Exposures of pink till, which characterize the Bloomington Drift, are common in road cuts. From here on, the route crosses drift deposited by Wisconsin glaciers.

133.8 Gravel pit on left.

137.0 Turn right at junction with Rt. 91.

137.4 Continue straight ahead (east) on Rt. 174 at junction of Rts. 91 and 174.

139.1 Enter Alta, prepare to make a sharp left 1000 feet ahead.

139.3 Turn left (north) at grain elevator, follow blacktop road east.

At Alta, the road rises nearly 100 feet onto the Providence Moraine, part of the Bloomington Morainic System. The more undulating surface of the Wisconsin drift, compared to the Illinoian, can be seen on this moraine. After crossing the crest of the moraine, one can see ahead the Illinois Valley. The broad expanse of the Illinois River called Peoria Lake results from partial damming of the valley by a large alluvial fan at the mouth of Farm Creek at East Peoria. The highway descends into the valley where the bluffs, nearly 400 feet high, are entirely glacial drift and are dissected by numerous steep-sloped valleys.

- 140.6 Turn left (north) at junction with Rt. 88.
- 141.0 Turn right (east) on Peoria County Rd. No. 64 (Mossville Rd.).
- 142.4 Descend Illinois River bluff.
- 143.4 Enter Mossville.
- 143.7 Turn left (north) at junction with State Rt. 29.

In the Illinois Valley, the highway follows the edge of a sand and gravel terrace eroded by a great flood of glacial meltwater called the Kankakee Flood, which was diverted into the Illinois Valley from the Valparaiso glaciers in Wisconsin, Indiana, Michigan, and Illinois about 14,000 radiocarbon years ago. The Kankakee Flood, although of short duration, covered the bottomland from bluff to bluff, greatly widening the valley. Sand deposited by the flood waters was blown into dunes that can be seen along the left (northwest) side of the highway.

- 145.4 Caterpillar Tractor plant on left.
- 149.2 Cross Rome Rd.
- 150.9 Chillicothe corporate limit.
- 153.4 Bridge over Henry Creek.
- 158.7 Hydraulic Press Brick Company plant on right.
- 160.0 Enter Sparland.
- 160.3 Cross State Rt. 17.
- 162.0 Gimlet Sandstone Member of the Modesto Formation exposed along left side of road.
- 162.5 Danville (No. 7) Coal was mined in bluff on the left.
- 167.3 Cross State Rt. 18 in Henry.

Henry is also on a large terrace eroded by the Kankakee Flood. From here to Hennepin, the bluffs are entirely glacial drift and the bedrock surface is 150 to 200 feet below the surface of the terrace.

- 172.5 Pass through Putnam.
- 176.7 Turn on to Interstate 180 at junction.
- 177.7 Bear right (east) on Interstate 180.
- 180.4 Cross Illinois River into Hennepin. Jones and Laughlin Steel Company complex on right.

Hennepin, like Henry, is located on a broad terrace of sand and gravel whose surface was eroded by the Kankakee Flood. Sand dunes occur on the terrace and along the road east of Hennepin. The dunes can be seen on the bluffs and the margin of the upland where they have migrated from the terrace area.

- 182.3 Interstate 180 ends, continue east on State Rt. 71.

- 185.8 Refuse pile on left; the refuse piles seen for the next 6.4 miles are from longwall mines, which operated in the Colchester (No. 2) Coal.

The northern Illinois field was an important coal-producing area of Illinois from 1875 to about 1915. Mining was conducted principally in the relatively thin Colchester (No. 2) Coal by longwall methods, resulting in a high production of refuse material. Roof and floor strata were mined to provide headroom in the entries. Large refuse piles, many now red-burned, are prominent topographic features on the level prairie. Thicker, more easily mined coals in southern Illinois lured many of the mining operators away from the northern area, and production began to decline after about 1915. Now only 1 mine is active in northern Illinois, the Peabody Coal Company, Northern Illinois Mine (strip), which is operating in the Colchester (No. 2) and the Sumnum (No. 4) Coals. (STOP NO. 10).

- 186.4 Enter Granville.

- 188.4 Cross Rt. 89, refuse pile on right.

- 189.2 Pass through Standard.

- 192.2 Pass through Cedar Point, refuse pile on left.

- 195.3 Cross Rt. 51.

- 197.1 Enter Oglesby, continue on Rt. 71, passing through Jonesville.

- 198.5 Turn sharp right on Rt. 71 (in Oglesby).

- 198.9 Outcrops on both sides of road and quarry just ahead on the right are in the La Salle Limestone Member of the Bond Formation. This is the stone used by the cement plants in this area.

- 202.1 Cross Rt. 178 and continue ahead 1 mile on Rt. 71. Watch for entrance road to Starved Rock.

- 202.8 Starved Rock State Park entrance road. Enter park and follow signs to Starved Rock Lodge.

Starved Rock, a large rock hill composed of Ordovician St. Peter Sandstone, is steeped in Indian legend, deriving its name from a tale of the mass starvation of an Illinois Indian band trapped on top of the rock by the Pottawatomi during the last half of the 18th Century. Early French explorers recognized the potential value of commanding this prominent feature. First were Louis Joliet and Father Marquette in 1673. After claiming the Mississippi from head to mouth for the King of France, the famous explorer La Salle left his trusted aide, Tonti, to build a fort on top of Starved Rock. This fort (Ft. St. Louis) served the French for several years as a trading post (mainly furs from the Indians) before being abandoned in 1690. Legend has it that Tonti buried a chest of gold on the rock.

In several sharp ravines throughout the park, one can see the Cheltenham Clay Member of the Spoon Formation just below the underclay of the Colchester (No. 2) Coal Member in disconformable contact with the St. Peter Sandstone. In places along the crest of the La Salle Anticlinal Belt, this disconformity is obviously an angular unconformity with the underlying rocks showing greater dip.

At Starved Rock, the Illinois River occupies a narrow, rock-walled, late Wisconsinan channel which is a contrast to the broad valley, half-filled with alluvial deposits, dating from early Pleistocene seen at Hennepin. In this region, the early glacial drainage occurred along the Ticona Valley, about 4 miles south of the Illinois Valley. The Ticona Valley is broader, nearly 100 feet deeper, and so completely buried by glacial drift that its position is not reflected in the present topography.

The position of the present river seems to have been determined by subglacial drainage channels that existed during the building of the Wisconsin moraines 16,000 to 18,000 radiocarbon years ago. The Kankakee Flood widened and deepened the valley to about the top of Starved Rock. The flood waters spread over the uplands between the moraines and established the channel that isolated Starved Rock. Later, the valley was deepened to the general level of the bedrock floor by the Chicago Outlet River of Glacial Lake Chicago. Several bedrock escarpments about 40 feet high that crossed the valley were waterfalls retreating up the valley, as shown by large gravel-filled potholes at the escarpment bases. The Chicago Outlet River spread from bluff to bluff and locally deposited coarse, cobbly gravel derived from erosion of the Silurian dolomite in the outlet channel at Chicago. After the last major discharge from Lake Chicago, less than 6,000 radiocarbon years ago, the river entrenched itself in a narrow channel in the rock floor.

END OF THE FIRST DAY

STARVED ROCK STATE PARK TO SOUTH WILMINGTON

TUESDAY, NOVEMBER 10, 1970

0.0 Leave Starved Rock Lodge. Exit from main gate onto State Rt. 71.

0.7 Turn right on Rt. 71.

1.5 Turn left (south) on Rt. 178 at junction with State Rt. 178.

2.4 Mathiessen State Park entrance on right.

5.3 STOP NO. 7. LOWELL SECTION.

Turn around in parking area and recross the Vermilion River heading north on Rt. 178.

On the steep, north-facing cutbank of the Vermilion River just west (downstream) from the highway bridge at Lowell, there is an exposure about 115 feet high. Here strata from the Pennsylvanian-Ordovician unconformity to the Vermilionville Sandstone Member, overlying the Springfield (No. 5) Coal, are well exposed. The section has been described by Cady (1919); a more detailed description was made by Willman and Payne (1942), who named the Lowell Coal Member from this locality and established the Lowell Cyclothem.

This locality is on the west flank of the La Salle Anticlinal Belt. In places, the Colchester (No. 2) Coal is only 4 feet above the Ordovician Galena Dolomite, which can be seen in the river bed. At the top of the bluff is the Vermilionville Sandstone, the basal unit of the Brereton Cyclothem. The Colchester (No. 2) Coal is 38 inches thick and has been mined out locally. It is overlain by 15 feet of the badly slumped Francis Creek Shale Member, which contains a few sideritic concretions and is overlain by the Mecca Quarry Shale Member. This shale is black, sheety, and hard, and contains numerous phosphatic lenses and nodules which give a distinct pimply appearance to the surfaces of the bedding planes.

The fauna consists principally of coprolites and vertebrate remains; Petrodus and Listracanthus are common. A better opportunity to examine the Mecca Quarry Shale and the overlying Oak Grove Limestone beds will be afforded at outcrops in the clay pits across the river (Stop 8 of the Road Log).

The Oak Grove Limestone Member is represented by a shale-limestone sequence. The limestones are dark gray, discontinuous, lenticular, or nodular, slightly fossiliferous, and septarian. These lenticular limestones cannot be correlated with any assurance to any unit of the Oak Grove Limestone in western Illinois. The Oak Grove Limestone and shale units are overlain by a 6-inch stigmarian siltstone with plant impressions and fusain streaks common throughout. The Lowell Coal and its underclay overlie the stigmarian siltstone. The coal is locally 5 inches thick and contains several shaly bands. The remaining unit of the Lowell Cyclothem consists of 16 feet of shale, which contains 2 limestone bands. The lowest of these limestone bands (6 feet above the Lowell Coal) is septarian, nodular and fossiliferous, with abundant Marginifera.

The Pleasantview Sandstone Member is represented by 3 feet of calcareous, sandy siltstone. The Breezy Hill Limestone Member (Nance, this Guidebook, p. 75) overlies the siltstone. This limestone is light gray, sandy, clayey, and weathers whitish. The Sumnum (No. 4) Coal is represented either by a thin coaly streak or is absent at the locality; however, its underclay is represented by 7 feet of gray calcareous clay. This clay is overlain by the Excello Shale Member, which is siliceous, black, hard, and "slaty," forming a prominent ledge.

Overlying the Excello Shale is the Hanover Limestone Member. In the lower part, the limestone contains medium gray to green shale with interbedded siltstone bands. The limestone is argillaceous, light greenish gray, nodular, and contains abundant productid brachiopods and crinoid stems. The upper part of the Hanover Limestone consists of a claystone layer (2 feet 3 inches thick) with many small, rough-surfaced limestone nodules containing Marginifera, and is overlain by the 1-inch thick

Covel Conglomerate Member. This limestone conglomerate is composed of limestone particles cemented by sparry calcite and pyrite. The Springfield (No. 5) Coal horizon just above the Covel Conglomerate is marked by a shaly, black, fossiliferous limestone band 1 inch thick, and is overlain by a prominent bed 2 feet, 2 inches thick of black, sheety, "slaty" shale, containing thin phosphatic lenses and small limestone concretions. Aviculopecten are abundant near the base. The Canton Shale Member and Vermilionville Sandstone Member complete the section.

5.5 Turn sharp left onto gravel road leading to clay pits.

5.6 STOP NO. 8. RISTOCRAT CLAY PIT.

In this clay pit, the refractory clay below the Colchester (No. 2) Coal Member, as well as the Francis Creek Shale Member overlying the coal, are mined for brickmaking. The units exposed (fig. 14) are the same as those in the lower part of the exposure on the opposite (south) side of the Vermilion River (Stop 7), but are better exposed and more easily accessible for study.

The No. 2 Coal and the underclay sequence beneath it are well exposed. The underclay contains limestone nodules (up to 3 feet in diameter) with an unusual radiating texture that resembles cone-in-cone structure. In the overlying Francis Creek Shale, a pelecypod fauna can be observed in the lowest few inches and a 4- to 6-inch darker gray zone at the top contains a mixed fauna of brachiopods and pelecypods. The remaining 18 feet of the Francis Creek Shale is light gray and uniform in texture.

5.7 Return to Rt. 178. Turn left and proceed north.

8.2 Mathiessen State Park entrance on left.

9.2 Cross Rt. 71. Continue on Rt. 178.

9.8 Outcrops of St. Peter Sandstone on both sides of the road.

10.1 Turn right into Starved Rock State Park. St. Peter Sandstone is well exposed throughout park.

STOP 9. LUNCH.

After lunch retrace route back to Rt. 178.

10.1 Turn right onto Rt. 178. Cross Illinois River into Utica.

10.6 Quarry on left in Shakopee Dolomite (Ordovician).

11.4 Turn left on Rt. 178. Follow marked route through Utica and ascend the north wall of the Illinois River Valley.

After crossing the Illinois Valley at Utica, the route rises into the flat plain of Lake Ottawa, an upland area inundated and leveled by the Kankakee Flood. Soon after crossing the Fox River, which is entrenched in St. Peter Sandstone, the highway rises onto the Marseilles Morainic System, the crest of which is 175 feet above the Lake Ottawa plain. The characteristic knobby topography of the Wisconsin moraines can be seen.

12.8 Cross U. S. Rt. 6; proceed ahead on Rt. 178 to Interstate 80.

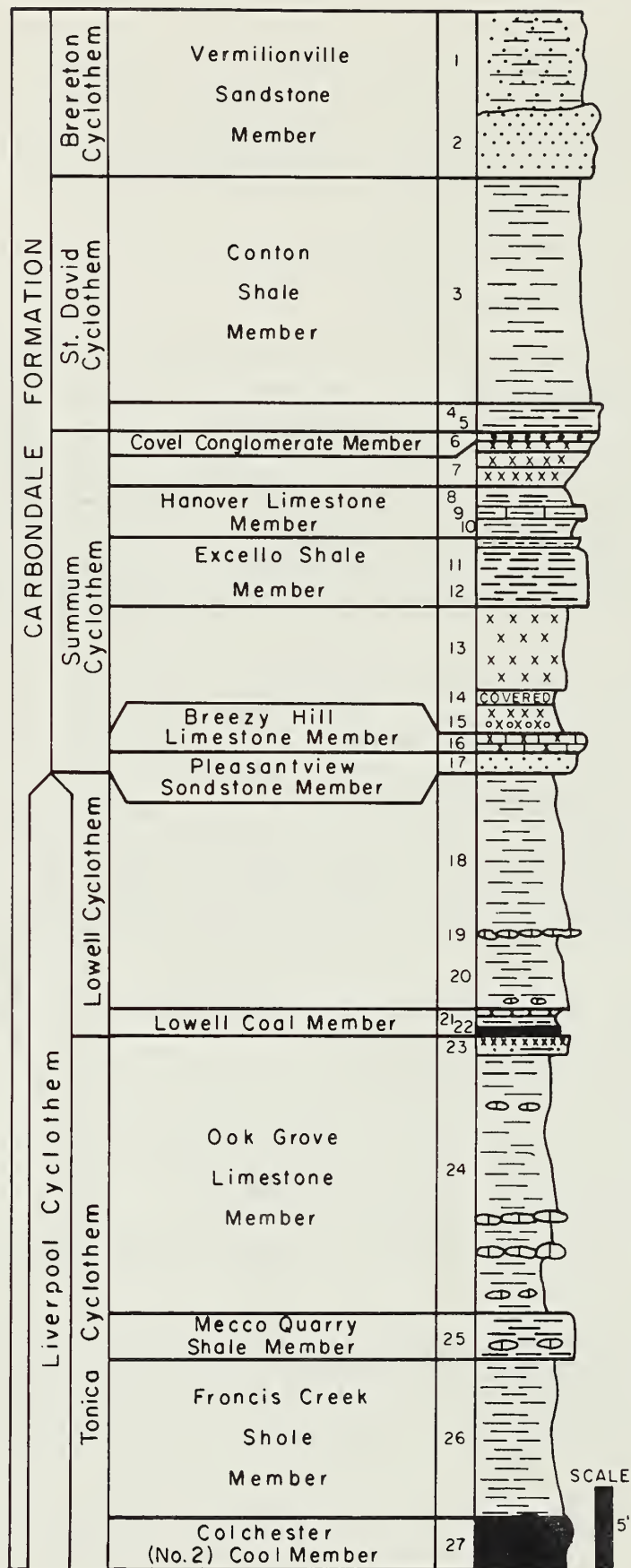


Fig. 13 - Columnar section, steep cutbank on south side of the Vermilion River $\frac{1}{4}$ mile west of Route 178 at Lowell. SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 8, T. 32N., R. 2E., La Salle Quadrangle.

FIGURE 13 EXPLANATION

1. Sandstone - brownish gray, thin bedded; interbedded with sandy shale; contains many black carbonaceous partings.
2. Sandstone - brown, fine-grained, poorly sorted, occurs in one massive bed.
3. Shale - gray, lower part fossiliferous (gastropods); contains layers of discoid septarian fossiliferous ironstone concretions; grades into underlying shale.
4. Shale - black, well-bedded, hard, "slaty," contains thin phosphatic lenses and laminae especially in lower part, occasional gray limestone nodule up to 1" thick; contains Aviculopecten in lower part.
5. Shale - black, very calcitic and fossiliferous; Marginifera and crinoid debris, pyritic.
6. Conglomerate - composed of poorly sorted fine-grained limestone particles (< 10 mm) in a pyritic matrix, fossiliferous.
7. Claystone - medium dark gray, becomes lighter in color downward with some mottling, reddish in lower 10", contains irregular calcitic masses up to 1" thick in bottom 1'9"; calcite throughout.
8. Shale - light gray, fossiliferous, as below; contains several lenticular limestone units up to 3" thick.
9. Limestone - light greenish gray, impure, nodular in lower part, fossiliferous, abundant productids and crinoid stems.
10. Shale - medium gray, slightly green.
11. Shale - medium dark gray, mottled with greenish gray; interbedded with medium gray, thinly laminated siltstone beds up to 3" thick.
12. Shale - black, smooth, well laminated, relatively soft, coaly in parts.
13. Claystone - medium olive gray, relatively firm and calcitic especially in lower 4'; a few small slickensided surfaces.
15. Claystone - light greenish gray, yellowish cast, silty, noncalcareous, contains sandy limestone nodules up to 1" thick in the lower 8".
16. Limestone - light greenish gray, sandy, clayey, massive.
17. Sandstone - light greenish gray, fine-grained, calcitic, clayey, thin-bedded.
18. Shale - light greenish gray, fine macaceous, sandy near top, contains small nodules of sandy gray limestone which weather rusty, contains an 8" mottled, soft red and green shale 1' from base, interval mostly covered.
19. Limestone - light gray, weathers reddish in part, septarian, fossiliferous; Marginifera, abundant, Mesolobus, Ambocoelia; forms a consistent nodular bed.
20. Shale - medium gray, weathers tan, soft, slightly fossiliferous, contains several siderite nodules in lower part, contains a 7" zone of light olive gray, lithographic septarian limestone nodules 2'4" from base, base 14", poorly bedded.
21. Shale - dark gray, fossiliferous, Mesolobus, Marginifera, Neospirifer.
22. Coal - contains several dull shaly bands.
23. Siltstones - medium dark gray, sandy, calcitic, micaceous; contains vertical plant impressions and charcoal streaks.
24. Shale - dark gray, sandy, micaceous, generally thick bedded, contains two prominent zones of lenticular semilithographic septarian limestones up to 1½' thick and containing a few fossils; several thinner and less persistent nodular limestone zones also present, a few crinoid stem fragments noted near base.
25. Shale - black, hard, "slaty," contains large discoidal concretions of dark gray limestone up to 6" thick, mostly in lower 1'.
26. Shale - light gray, soft, thin bedded; contains a few sideritic concretions; generally not exposed.
27. Coal - has been mined out locally.

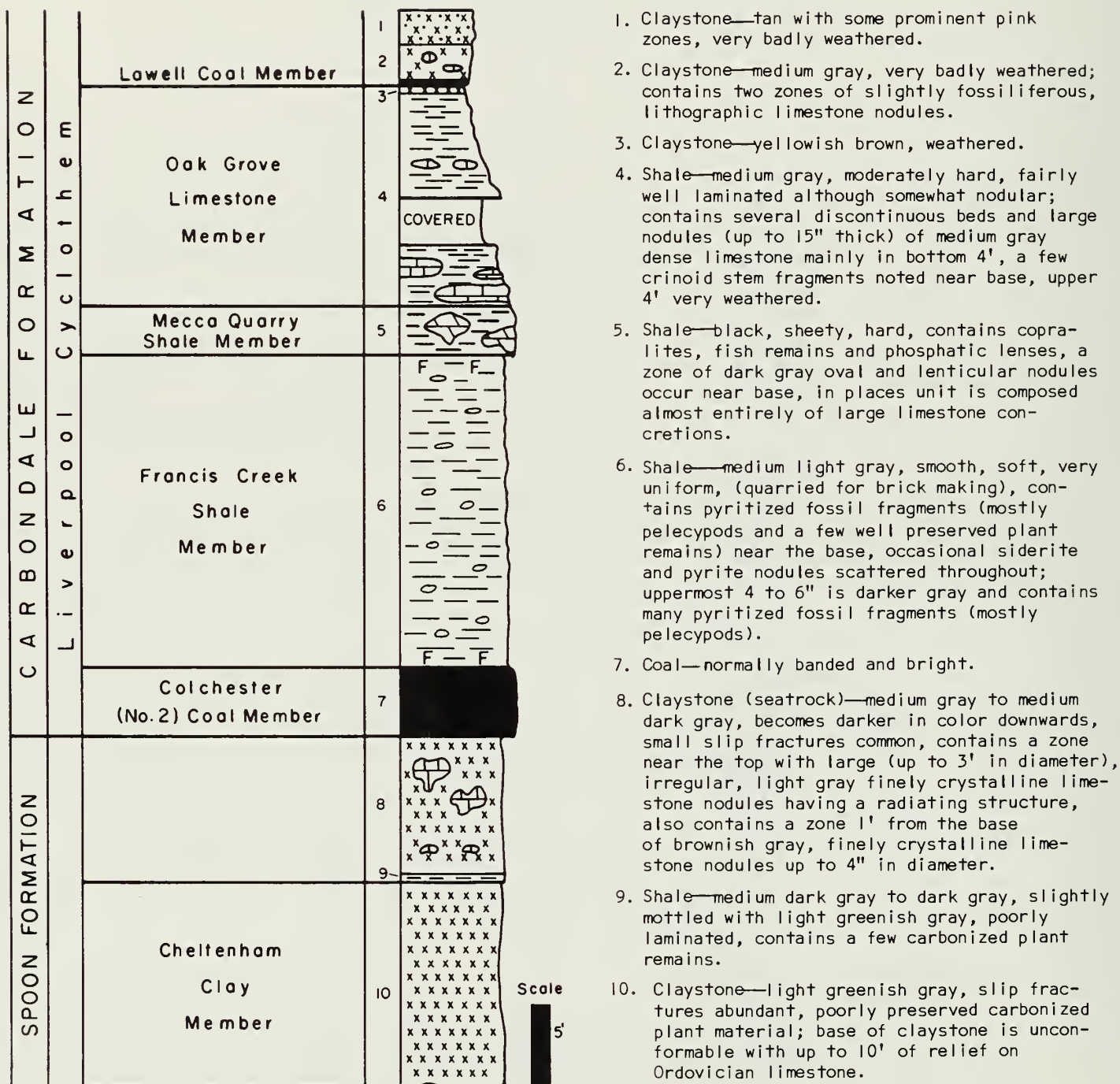


Fig. 14 - Columnar section, Ristocrat Clay Pit on north bank of Vermilion River at Lowell. NE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 8, T. 32N., R. 2E., La Salle County, La Salle Quadrangle.

13.3 Turn right onto Interstate 80. For the next 9 miles between here and the Ottawa exit, Interstate 80 lies parallel to the Illinois River about 1 to 2 miles north of it. Along the river, St. Peter Sandstone has been extensively mined for high silica sand. The No. 2 Coal and its underclay have also been strip mined at numerous places along the Illinois Valley between Utica and Ottawa.

22.3 Cross State Rt. 23. Ottawa, 2 miles south on the Illinois River, is the site of extensive mining operations in the high silica St. Peter Sandstone.

There is some disagreement among historians as to when the first report of coal in the New World actually took place. According to some, Father Hennepin located coal deposits near the present town of Ottawa in 1668, but most references credit Father Marquette and Louis Joliet with the discovery of coal in 1673. Joliet's map of 1674 indicates the location of "Charbon de terre" near the present city of Utica. Both of these occurrences are the Colchester (No. 2) Coal. Early writings indicated that the Indians used the coal for fuel.

24.9 Cross the Fox River. Its confluence with the Illinois River is 1 mile south.

28.9 Ascend the Marseilles Moraine, which is responsible for the morainal topography for the next 3 miles.

44.9 Cross State Rt. 47 north of Morris.

53.1 Cross Aux Sable Creek. Ascend the Minooka Moraine.

55.0 Minooka exit. Prepare to turn right off Interstate 80 onto Interstate 55, 4 miles ahead.

58.8 Cross Du Page River.

59.3 Turn right (south) onto Interstate 55.

After turning south on U. S. Route 66 (Interstate 55), the route crosses the Des Plaines Valley, and before reaching the river, crosses a high terrace, which is a remnant of the sand and gravel fill made by outwash from the Valparaiso glacier. The river is only slightly entrenched into the top of Ordovician and Silurian age limestone. The Des Plaines and Kankakee Rivers join to form the Illinois River in this broad bottomland 3 miles west of the highway. The glacial floodwaters in the Kankakee and Des Plaines valleys eroded much of the glacial drift; thus, bedrock is exposed in many areas.

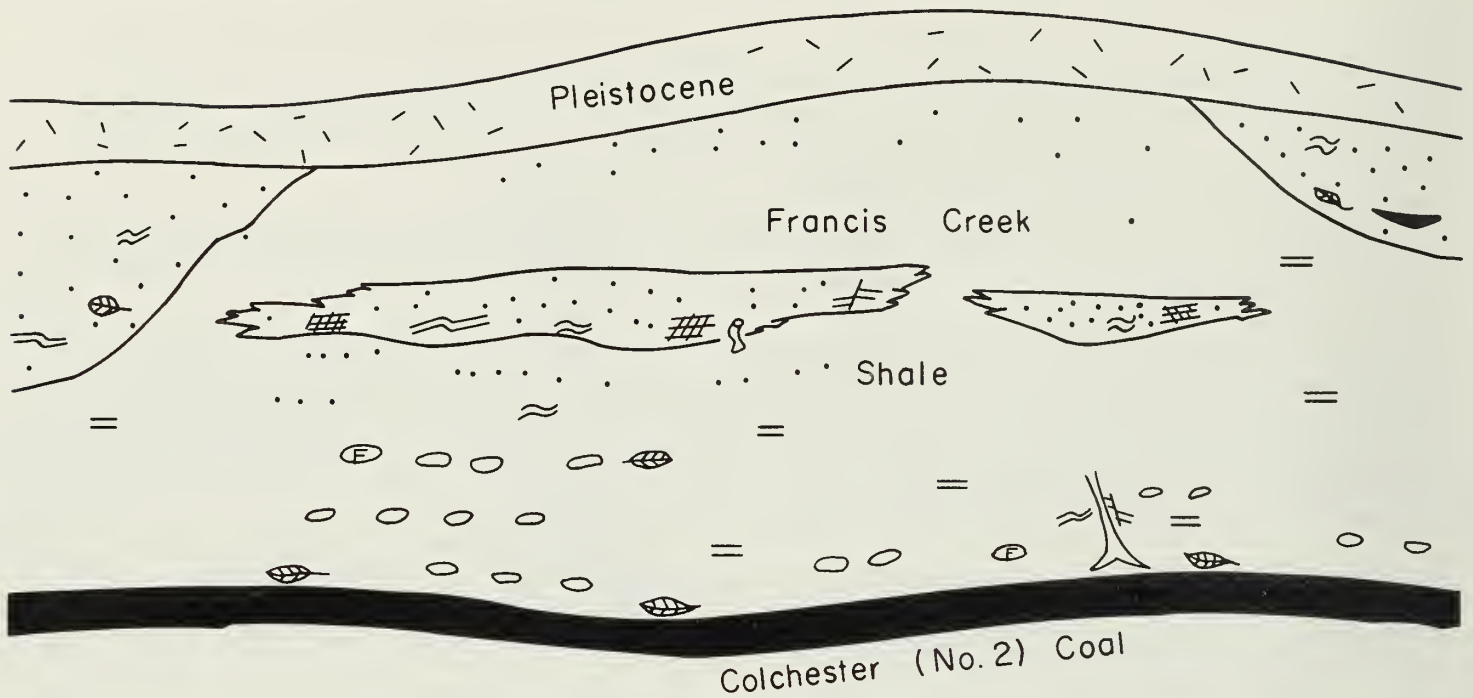
60.8 Cross Illinois-Michigan Canal.

64.0 Cross Des Plaines River, which connects Lake Michigan with the Illinois River by way of the Chicago Sanitary and Ship Canal and the Chicago River.

69.1 Cross Kankakee River. Prepare to make left turn off Interstate onto Rt. 129, 2 miles ahead.

71.5 Turn left onto Rt. 129. Strip mining ahead on left is in the Colchester (No. 2) Coal, which was strip mined 25 to 30 years ago. Most of this spoil area is now used for park and recreational purposes.

75.7 Turn left across railroad track at junction with State Rt. 113, then make right turn onto Rt. 53.



- | | | | |
|---|----------------|--|--------------------|
| F | Animal fossils | | Glacial drift |
| | Plant fossils | | Sandstone |
| | Buried tree | | Shale or siltstone |
| | Coal fragments | | Coal |
| | Burrow | | Concretions |

LAMINATIONS:

- | | |
|--|----------|
| | current |
| | parallel |
| | ripple |

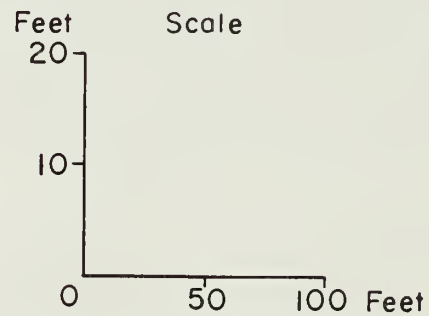


Fig. 15 - Diagrammatic section of highwall, Peabody Coal Company, Pit 11, near Braidwood, Illinois.

79.1 Turn left at Wilmington Coal sign onto mine entrance road leading to Peabody Coal Company, Northern Illinois Mine.

81.3 Turn left on haulage road to Pit 11.
STOP 10. PEABODY COAL COMPANY. PIT 11.

Large-scale strip mining in the Colchester (No. 2) Coal Member began in northern Illinois in 1928 in areas of thin overburden near the outcrop. Strip mining has continued to be an important industry in the Wilmington area since improvements in strip mining equipment have enabled the removal of increasingly thicker amounts of overburden from the relatively thin coal. Despite extensive past mining in the area, remaining reserves of 345 million tons of No. 2 Coal, with overburden thickness of 150 feet or less, have been mapped in Grundy, Will, and Kankakee counties (Smith, 1968).

At Pit 11 of the Peabody Coal Company, the No. 2 Coal averages about 3 feet in thickness, which is thicker than it is in most other areas in northern and western Illinois, where the average is 24 to 30 inches. The highwall consists of a thick section of the Francis Creek Shale Member, which is unconformably overlain by Pleistocene sands and tills. The lower portion of the Francis Creek Shale consists of light gray, silty shales, which locally contain lenticular sandstone bodies and in some places grade upward into a more persistent unit of sandstone lenses or channel sandstones (fig. 15). While this whole section is tentatively assigned to the Francis Creek Shale Member, the upper portion may be stratigraphically higher than any strata of the Francis Creek Shale in western Illinois (Smith, this Guidebook, p. 40). Shabica (this Guidebook, p. 47) has interpreted a distributary channel and bay environment of deposition for the Francis Creek Shale at this locality.

The Francis Creek Shale at Pit 11 contains a biota dominated by marine invertebrates (Johnson and Richardson, this Guidebook, p. 53), although plant fossils are also common (Peppers and Pfefferkorn, this Guidebook, p. 65). The northeastern Illinois mining area has long been an excellent collecting area for Pennsylvanian fossils, centering around the Mazon Creek exposures, in which plant fossils are dominant. In the most favorable Pennsylvanian fossil collecting localities, such as the Wilmington area, the fossils are preserved in siderite concretions. Concretions containing Mazon Creek fossils can be seen weathering out of the shale on the Pit 11 spoil heaps. Oxidation of the siderite causes the concretions to turn reddish brown, making them readily visible. Peabody Coal Company has recently excavated, under the direction of Shabica, a small quarry in the lower part of the Francis Creek Shale at Pit 11. Shabica found the siderite concretion layers to occur 2 to 9 feet above the Colchester (No. 2) Coal. Hopefully, we will be able to examine this quarry as well as the strata exposed in the highwalls at several locations. An opportunity will be provided for participants to collect concretions from the spoil piles and to examine a collection of representative fossils from the Francis Creek Shale.

End of Field Trip. Retrace route back to Interstate 55, and proceed to Milwaukee, Wisconsin via Interstates 55, 294, and 94.

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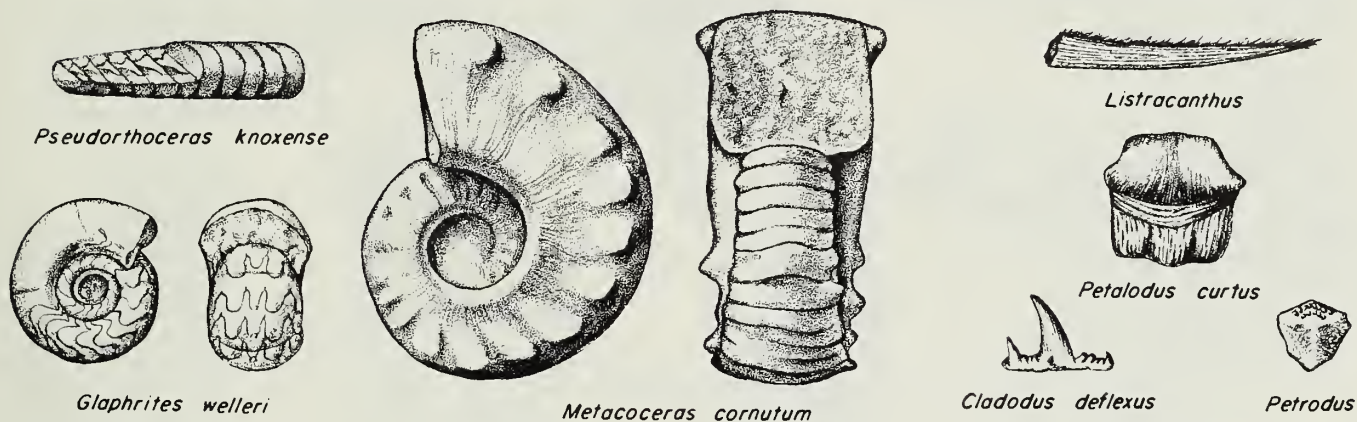
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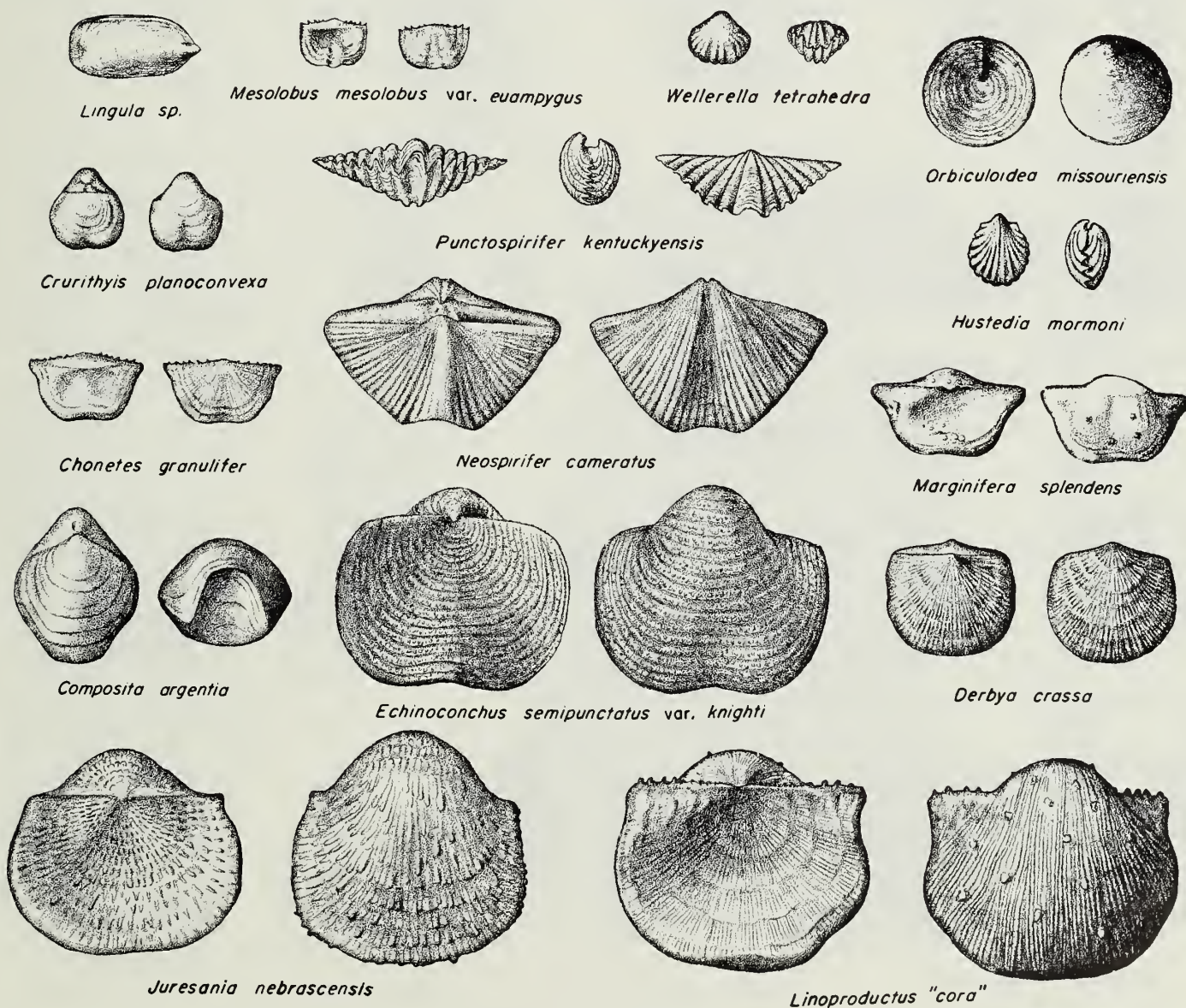
COMMON PENNSYLVANIAN FOSSILS

CEPHALOPODS

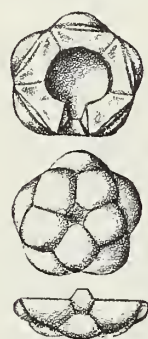
VERTEBRATES



BRACHIOPODS



CRINOIDS

*Delocrinus*

FUSULINIDS

*Fusulina girtyi**Fusulina acme*

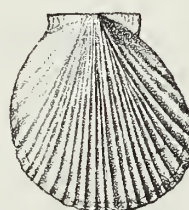
CORALS

*Lophophlidium proliferum*

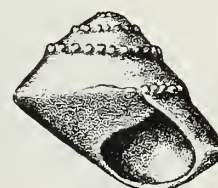
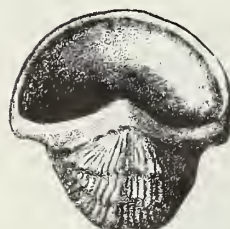
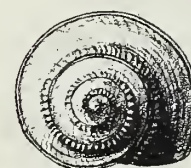
TRILOBITES

*Ameura sangamonensis* *Ditomopyge parvulus*

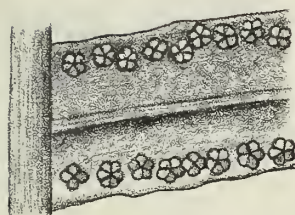
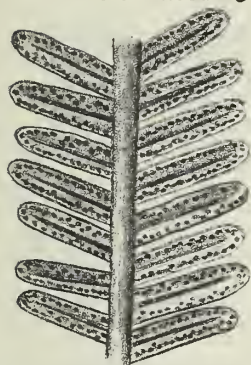
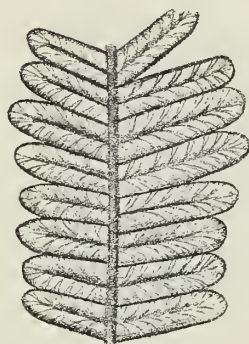
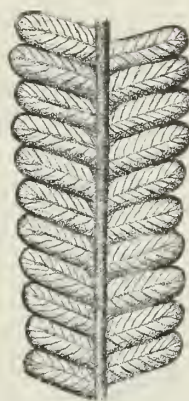
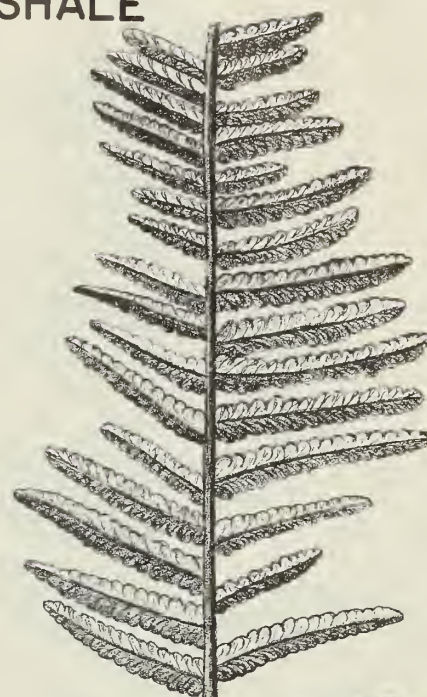
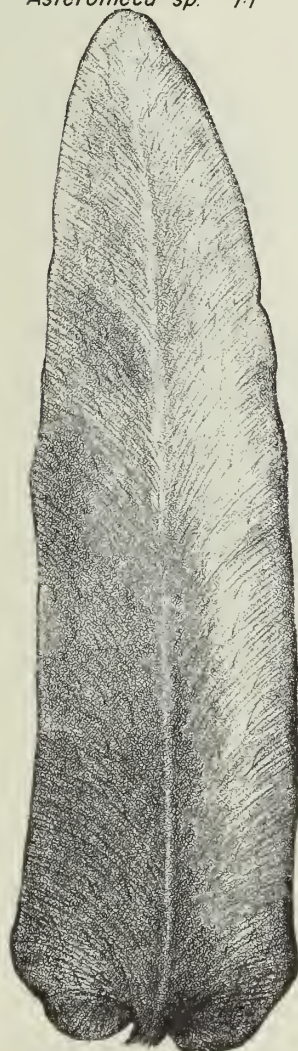
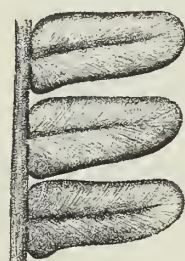
PELECYPODS

*Cardiomorpha missouriensis**Dunbarella knighti**Lima retifera**Myalina wyomingensis**Nucula (Nuculopsis) girtyi**Edmonia ovata**Astartella concentrica**Aviculopecten germanus*

GASTROPODS

*Naticopsis (Jedria) ventricosa**Euphemites carbonarius**Trepospira sphaerulata**Knightites montfortianus**Donaldina robusta**Sphaerodoma medialis**Glabrocingulum (Glabrocingulum) grayvillense*

FOSSIL PLANTS, FRANCIS CREEK SHALE

*Asterotheca* 5:1*Pecopteris* 5:1*Asterotheca* sp. 1:1*Pecopteris* sp. 1:1*Pecopteris unita* 1:1*Pecopteris* sp. 1:1*Neuropteris scheuchzeri* 1:1*Neuropteris rarinervis* 1:1*Neuropteris ovata* 1:1*Sphenophyllum* sp. 1:1*Alethopteris serlii* 1:1*Sphenopteris* sp. 1:1*Sphenopteris* sp. 1:1*Mariopteris* sp. 1:1

LITHOLOGY AND DISTRIBUTION OF THE FRANCIS CREEK SHALE IN ILLINOIS

William H. Smith
(Illinois State Geological Survey)

INTRODUCTION

The Francis Creek Shale Member of the Carbondale Formation is a "clastic wedge" of sediments ranging in grain size from clay to fine sand and ranging from 0 to a thickness of 80 feet or more. These rocks were locally deposited immediately following the deposition of the Colchester (No. 2) Coal Member and preceding the deposition of the Mecca Quarry Shale Member. The Mecca Quarry Shale is a fissile, black, "slaty" shale that is much more widespread regionally than the Francis Creek Shale. It immediately overlies the No. 2 Coal where the Francis Creek is absent and overlies the Francis Creek, except where the shale approaches its maximum thickness.

The environment of deposition of the Francis Creek Shale is described by Shabica (this Guidebook, p.43), the flora by Peppers and Pfefferkorn (this Guidebook, p.61), and the fauna by Johnson and Richardson (this Guidebook, p.53). The purpose of this paper is to describe the distribution, thickness, and lithologic relationships of the Francis Creek Shale over the area of its occurrence in Illinois. In an earlier study, which consisted of environmental mapping of each of the beds in the Liverpool Cyclothem, Wright (1965) mapped the extent of the shale over the Interior Coal Province (fig. 1). A more detailed map of the Francis Creek Shale in Illinois, based on additional data, is included in this report.

STRATIGRAPHIC RELATIONSHIP

The Francis Creek Shale was named by Savage (1927) from exposures along Francis Creek, Section 22, T. 5N., R. 1E., Fulton County, Illinois. The shale is medium to medium light gray, and although it does not generally exceed 20 feet in thickness, in several areas it does become much thicker. It is uniform in composition both laterally and vertically, and has been used locally for brick manufacture in western and northern Illinois.

The Francis Creek Shale of northern Illinois is correlated (fig. 2) with strata of similar lithologic and stratigraphic relationships that occur as far west as Kansas and Oklahoma, and eastward into Indiana and west Kentucky (Wright, 1965). The Mecca Quarry Shale Member overlies the Francis Creek Shale in all areas except northeastern Illinois, where the Francis Creek is often very silty and locally contains lenses and channel fillings of fine grained sandstone.

Over most of the area of its occurrence throughout the Interior Coal Province (fig. 1), the Francis Creek is directly overlain by fissile black shale similar to most black roof shales that closely overlie coals. This black shale, where it occurs in west central Indiana, was the subject of a detailed ecological study conducted over a period of several years by Zangerl and Richardson (1963), who named it the Mecca Quarry Shale, from the village of Mecca, Parke County, Indiana. The type locality (SW $\frac{1}{4}$, NE $\frac{1}{4}$, Section 29, T. 15N., R. 8W.) is designated from the locality where Zangerl and Richardson excavated a small quarry for study into the shale along the outcrop. Since this same shale is very extensively developed in Illinois, the name Mecca Quarry Shale Member of the Carbondale Formation is extended into Illinois, where it is overlain by the Oak Grove Limestone Member and underlain by either the Francis Creek Shale or the Colchester (No. 2) Coal Members.

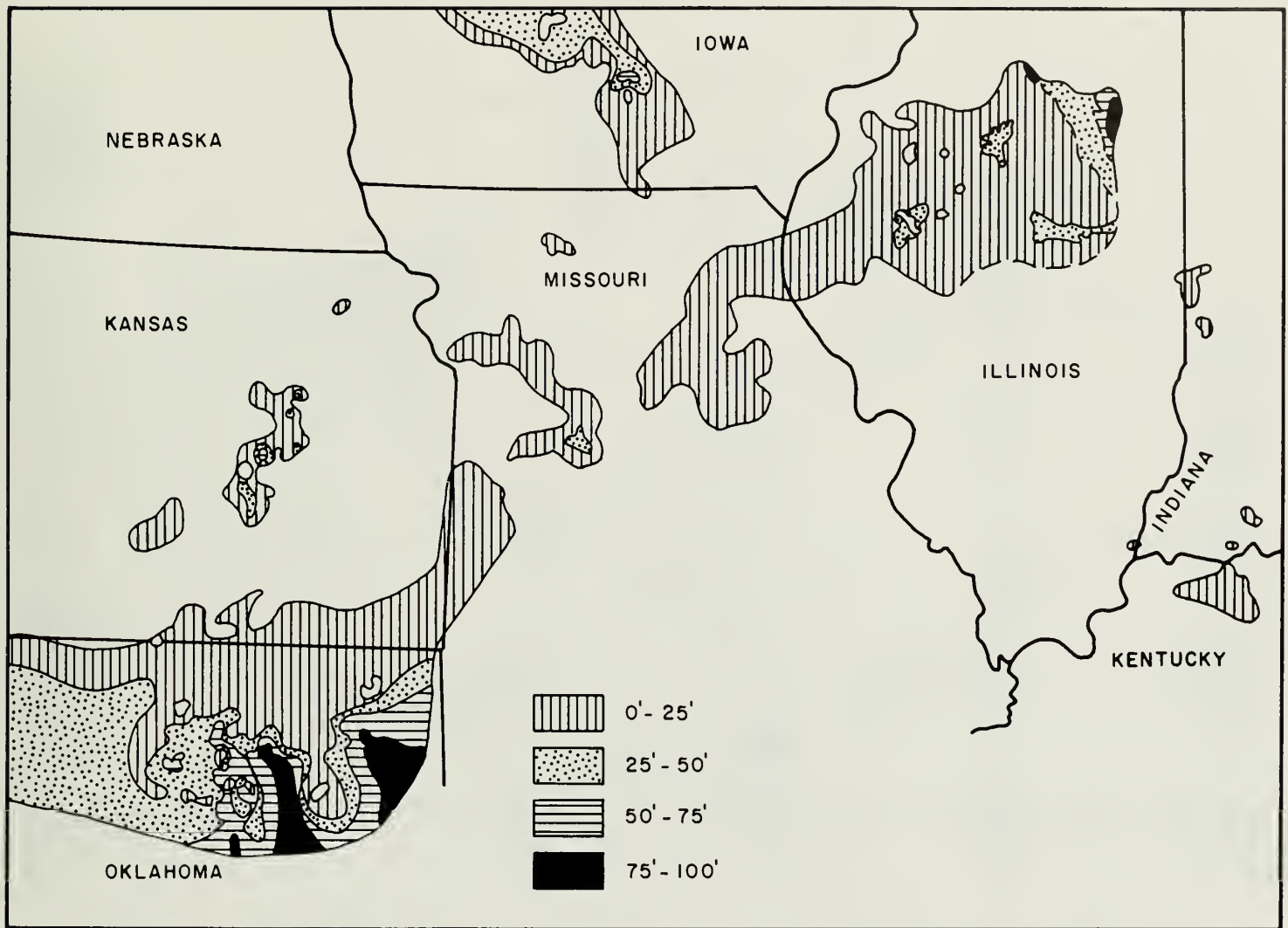


Fig. 1 - Distribution and thickness of the Francis Creek Shale in the Interior Coal Province, after C. R. Wright (1965) with some modifications in Illinois to conform to figure 3 of this paper.

THICKNESS OF FRANCIS CREEK SHALE

The isopach map (fig. 3) shows the regional variations in thickness of the Francis Creek Shale. In western Illinois it is widely distributed and ranges from 0 to 20 feet in thickness, except in a south-east to northwest trending belt through Brown, Schuyler, and southern Fulton counties where it is often between 20 and 30 feet thick. In 3 areas of northern and northeastern Illinois the shale becomes 80 feet or more thick. The largest of these areas is along the northeastern outcrop in the Wilmington area (Route map of Road Log, second day). In the strip mines near Wilmington, both the Mazon Creek Flora (Peppers and Pfefferkorn, this Guidebook, p. 61) and the Mazon Creek Fauna (Johnson and Richardson, this Guidebook, p. 53) occur in the area of very thick Francis Creek Shale. In all the strip mines in the No. 2 Coal in northeastern Illinois, Francis Creek Shale, up to 60 feet or more thick, is the only bedrock (except local occurrences of Cardiff Coal to be discussed later) exposed above the coal in the highwall. The top of the shale is everywhere truncated by glacial drift.

Drill records south and west of the strip-mined areas provide the basis for mapping in the sub-surface. The distribution of drill hole data on which the isopach map (fig. 3) is based is shown in figure 4, which also shows the location of holes used to construct cross sections (fig. 5). These 2 cross sections illustrate the wedge-shaped nature of the Francis Creek Shale and its marked thickening in northeastern Illinois.

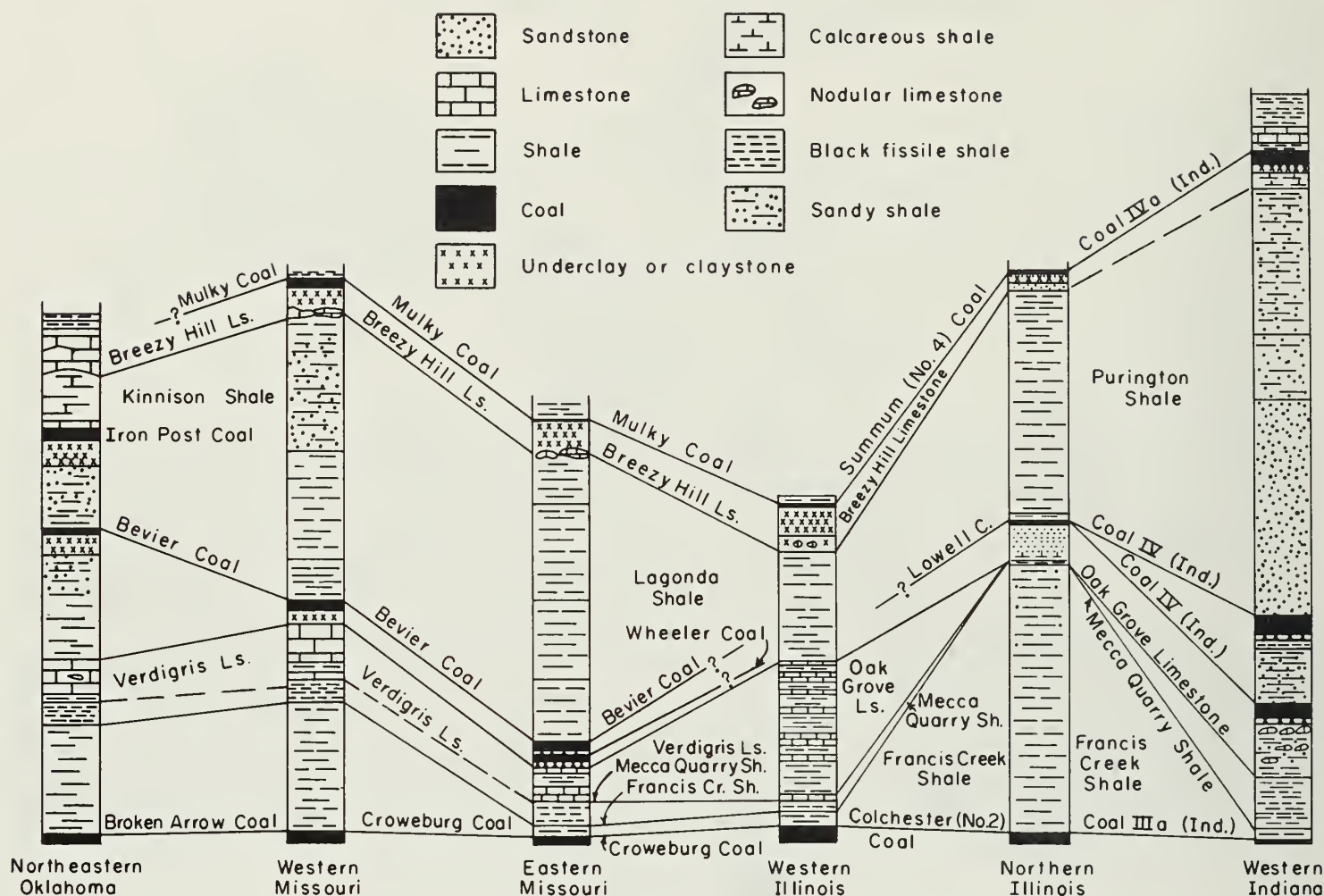


Fig. 2 - Correlation diagram of strata from the base of Colchester (No. 2) Coal and its correlatives to the top of Summum (No. 4) Coal and its correlatives from southeastern Oklahoma to western Indiana.

A characteristic feature of the Francis Creek Shale is the marked local variation in thickness. It is not possible to map all of the variations on the isopach map (fig. 3) or even on the much larger scale work map from which it was drawn; therefore, the thicknesses shown represent maximum thickness of the member observed or recorded in a local area.

As can be seen at the Banner Mine (fig. 5 of the Road Log, this Guidebook, p. 9), and at numerous outcrop and mine exposures, the Francis Creek Shale is very lenticular and may vary from 0 to nearly 15 feet in thickness within a distance of a few hundred feet or less. In many mines and outcrops where the Francis Creek Shale can be observed in detail, the upper surface of the underlying No. 2 Coal is undulating with many local irregularities in elevation of 10 feet or more. At the Ladd Mine in Bureau County, a contour map of the top of No. 2 Coal was made (Cady, 1915) which showed local variations in elevation of as much as 25 feet within 1000 feet horizontally. There are numerous references in the literature and in unpublished mine notes commenting on the local irregularity in elevation of the No. 2 Coal with a corresponding variation in thickness of the overlying Francis Creek Shale. One extreme example of such variation was revealed by underground mining operations 2 miles west of Coal City in Grundy County, where Cady (1915) and Culver (1923) described a local depression of 50 feet in a horizontal distance of 800 feet. Culver suggests that this depression may have been an original inequality in the depositional surface because he observed that the coal was more than 30 inches thicker than normal in parts of the depression than it was in surrounding areas.

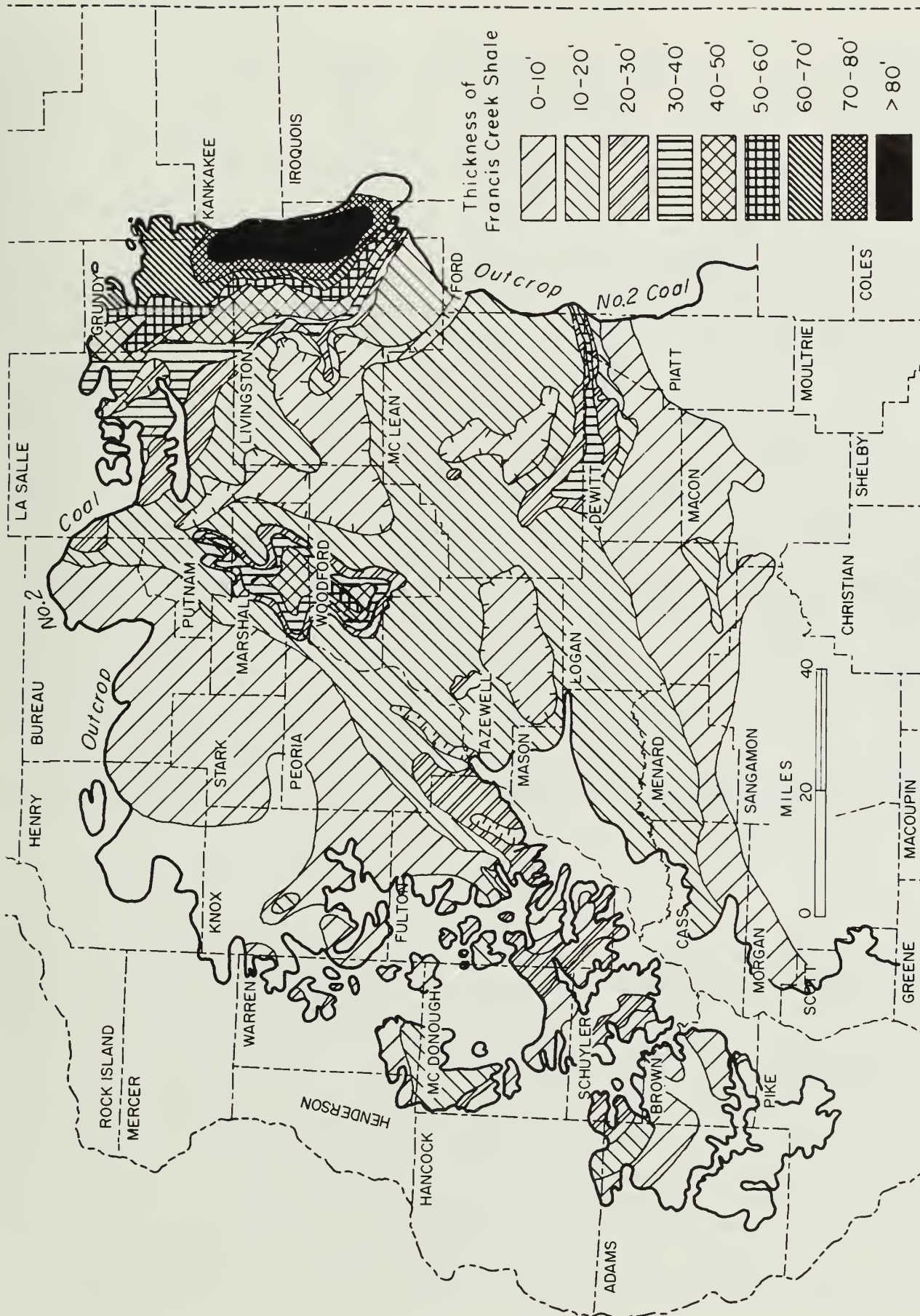


Fig. 3 - Isopach map showing regional thickness of Francis Creek Shale in Illinois.

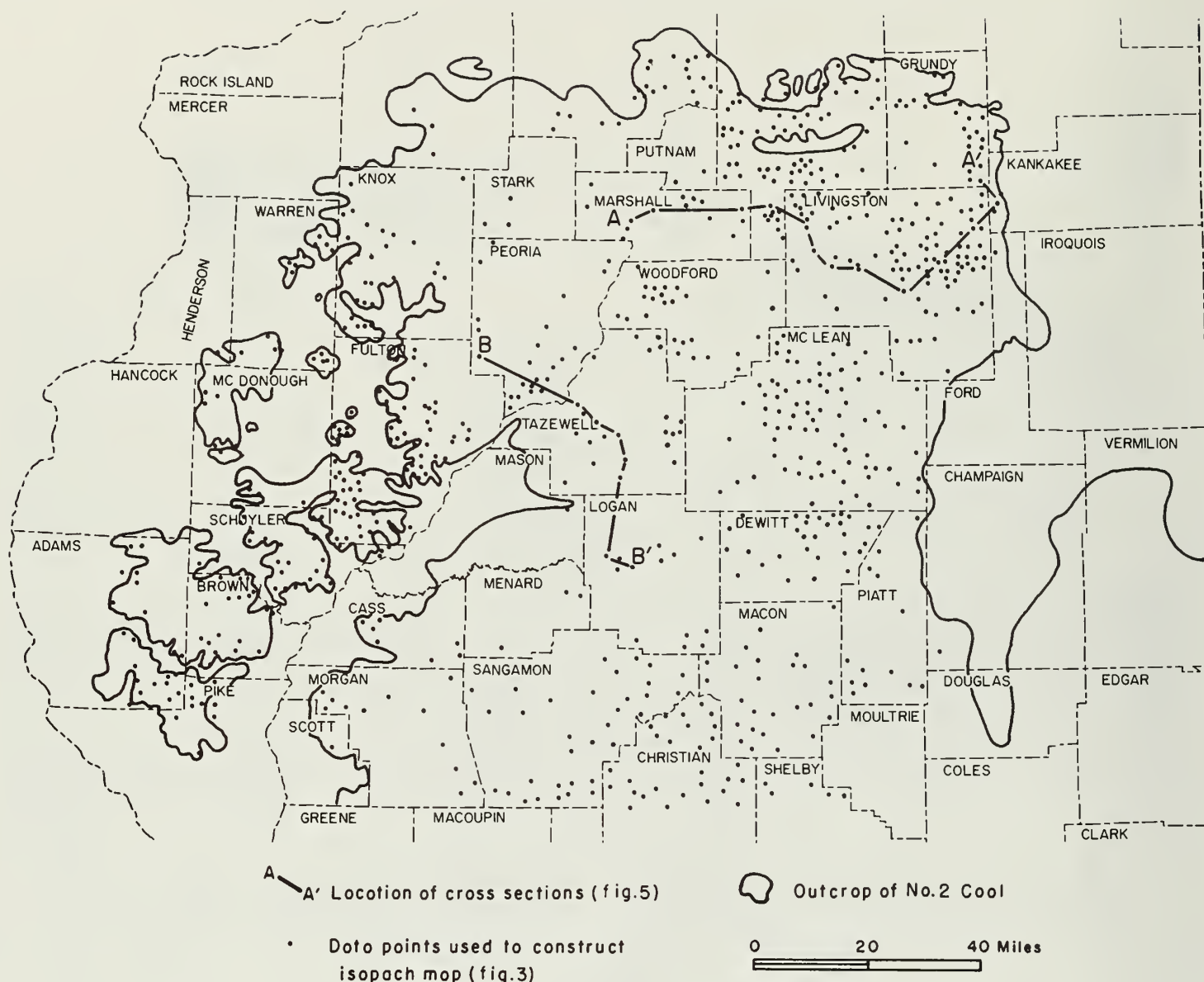


Fig. 4 - Distribution of control points used to construct isopach map (fig. 3) and cross sections (fig. 5).

The apparent relationship between lower amounts of pyritic sulfur in the No. 2 Coal where it is overlain by thicker Francis Creek Shale (from the United Electric Coal Companies Banner Mine, Hopkins and Nance, this Guidebook, p. 96) may also suggest that much of the local variation in thickness of the shale results from its rapid accumulation on top of the coal. Recent detailed study of the interface between the top of the No. 2 Coal and the overlying shale is described in this Guidebook by Gluskoter and Hopkins and by Damberger. They point out the probability that the Francis Creek Shale was deposited rapidly over the coal. This is evidenced by the well laminated pyritic shale which contains abundant large-plant impressions and pyritic replacements of plant material lying directly on, and somewhat gradational with, the topmost part of the coal (Damberger, this Guidebook, p. 100). The well preserved fossils found in the Francis Creek Shale (Johnson and Richardson, this Guidebook, p. 53) also suggest rapid deposition of this shale.

In contrast to somewhat gradational contact between the Francis Creek Shale and the No. 2 Coal described above, the contact between the Mecca Quarry Shale Member and the No. 2 Coal in areas of locally higher elevation (adjacent to where Francis Creek Shale accumulated in lows) shows a corroded surface at the top of the coal. Between the top of the No. 2 Coal and the Mecca Quarry

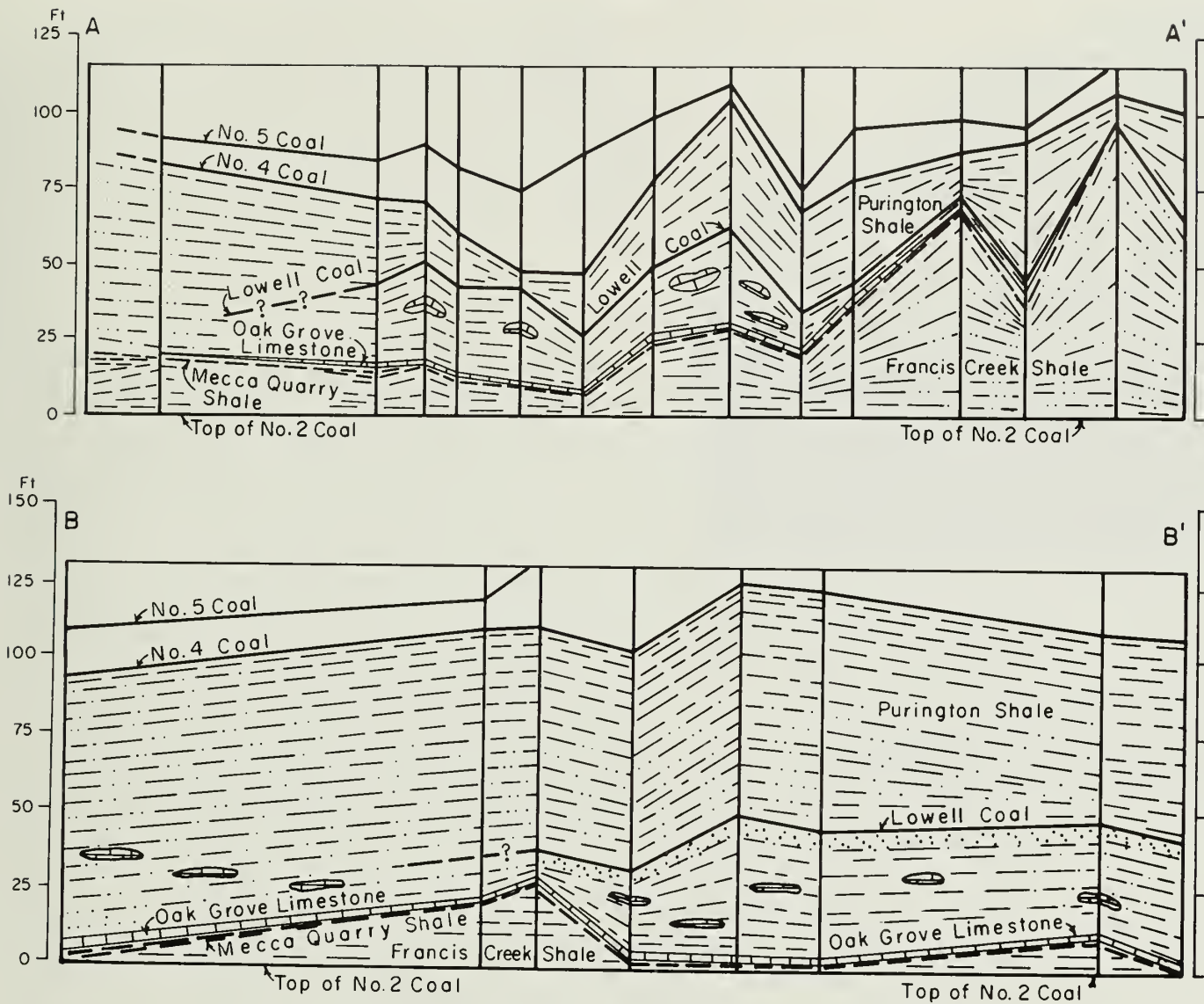


Fig. 5 - Cross sections showing thickness and stratigraphic relationships of Francis Creek Shale.

Shale there is often a thin phosphatic layer (Damberger, this Guidebook, fig. 1, p. 100), or fossil shell hash, similar to the material described by Zangerl and Richardson (1963) as a "transgression shell breccia," which they interpreted to have formed during inundation of the coal swamp by marine waters.

It appears to the writer that the fossil shell breccia described by Shabica (this Guidebook, p. 47), occurring in the top few inches of the Francis Creek Shale that is overlain by Mecca Quarry Shale, is approximately time equivalent to the thin shell breccia, or phosphatic layer (generally less than 1 inch thick), that occurs between the top of the No. 2 Coal and the Mecca Quarry Shale where the Francis Creek Shale is absent. The presence of a somewhat phosphatic shell breccia has been observed at the contact between the Mecca Quarry Shale and the No. 2 Coal at many places in Illinois and elsewhere in the Interior Coal Province beyond the limits of Francis Creek accumulation.

The thickest section of Francis Creek Shale overlain by the Mecca Quarry Shale known to the writer occurs in Section 2, T. 27N., R. 6E., Livingston County, where a core test on the east flank of the Pontiac gas storage structure contained 39 feet of Francis Creek Shale. There are abundant, well preserved plant impressions throughout this shale, which are overlain by 6½ inches of typical Mecca Quarry Shale (fig. 2, col. 5). Farther to the northeast, toward the Wilmington area of

No. 2 Coal mining, there are no exposures showing the upper contact of the Francis Creek Shale. Although there are no available cores, drill records southward from the area of strip mining suggest that the Francis Creek Shale, which is often described as thinly laminated siltstone or fine-grained sandstone, thickens to as much as 80 feet, and is closely overlain by what is interpreted to be the Lowell Coal Member. When more data becomes available in this area, it may be found that where the Francis Creek Shale Member is very thick, the upper part may be younger than the Francis Creek Shale in other parts of northern and western Illinois where the Mecca Quarry Shale and the Oak Grove Limestone overlie it.

LITHOLOGY

The Francis Creek Shale Member in northern and western Illinois appears to be a wedge of clastic rocks from a northern or eastern source deposited rapidly over the No. 2 Coal soon after coal deposition and before the deposition of the Mecca Quarry Shale Member. Where it is less than 30 feet thick (as it is over most of the area of its occurrence), the shale is a fine grained, well laminated, medium light gray shale of uniform lithology. It commonly contains a pelecypod fauna in the bottom few inches and a mixed fauna, mostly fragmented brachiopods and pelecypods, in a darker zone near the top. Siderite nodules are common and are fossiliferous in some localities. Depending on the environment of deposition, the nodules may contain plant compressions like those from the Mazon Creek locality (Peppers and Pfefferkorn, this Guidebook, p. 61), or they may contain marine vertebrate and invertebrate fossils (Johnson and Richardson, this Guidebook, p. 53). At many outcrops in western Illinois, however, the siderite nodules do not generally contain well preserved fossils.

In northeastern Illinois where the Francis Creek Shale Member thickens to as much as 80 feet or more, it is often composed largely of siltstone, and in some drill records and cores, there is a large proportion of fine grained sandstone. Lenses of fine grained sandstone are common in the upper part of the Francis Creek Shale in the strip mine highwalls at Pit 11 of the Peabody Coal

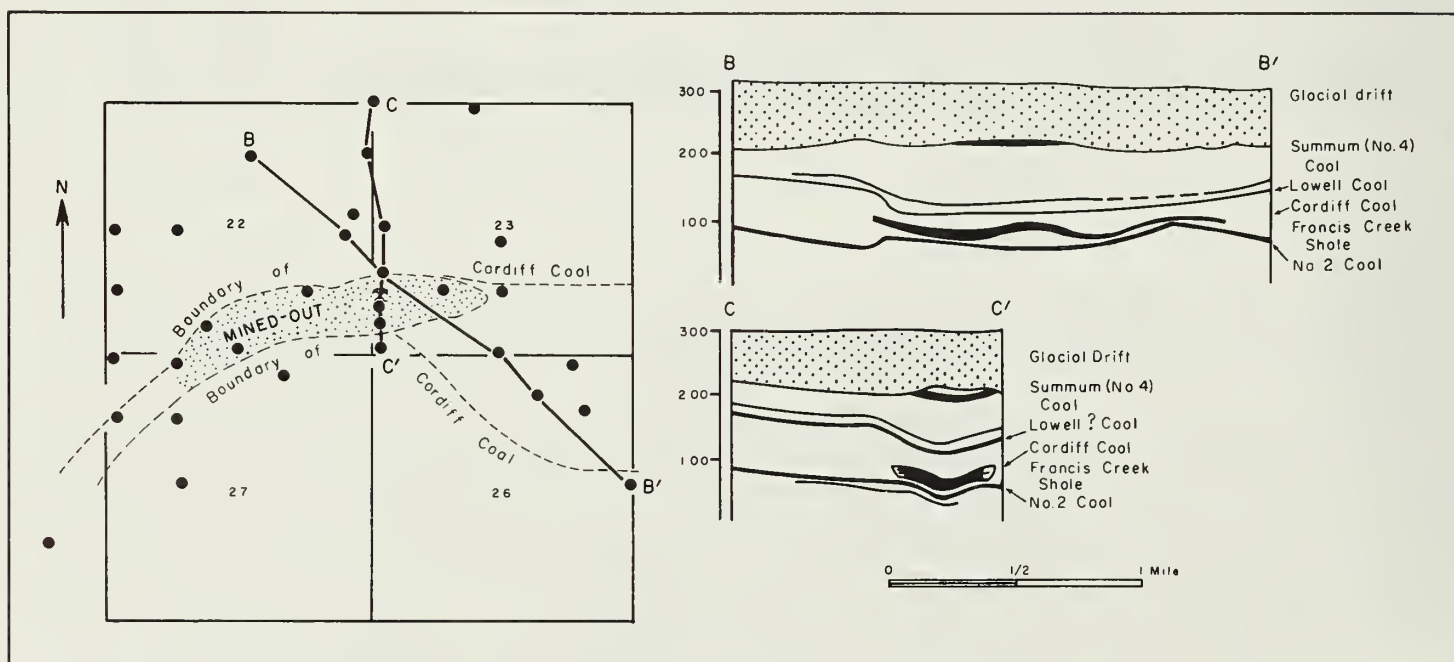


Fig. 6 - Sketch of crescent-shaped channel in the Francis Creek Shale from which Cardiff Coal up to 12 feet thick was mined. Cross sections at right angle and oblique angle across channel show the lenticular shape of the coal deposit. Modified from Cady (1915). Coal correlations added by W. H. Smith (1970).

Company Northern Illinois Mine. These sandstones, which contain coal and black shale inclusions, are interpreted as being distributary channel deposits and are described in detail by Shabica (this Guidebook, p. 47). Palynological study of spores taken from samples of rafted coal fragments associated with the sandstone channels (R. A. Peppers, personal communication, 1970) reveals them to be derived from the No. 2 Coal or, more likely, the Cardiff Coal.

Lenticular bodies of coal ranging up to 12 feet 2 inches thick and occurring as channel deposits interpreted to be in the Francis Creek Shale were mined about 1895 locally near Cardiff, SE $\frac{1}{4}$ Section 22, T. 3N., R. 8E., Livingston County. This unusual coal occurrence at Cardiff was described by Cady (1915):

The shape of the coal bed is strikingly lenticular and crescentic in cross-section. The edges of the bed dip strongly toward the trough possibly even more so than is indicated by the drawing. The feathering of the bed at the edges as shown in cross-section (fig. 6) represents the conditions as shown in the drilling records; it is reported however that the bed tapers out on either side rather than feathers out, the bottom of the bed rising toward the top. There was possibly about 600 to 1000 feet of relatively flat-lying coal north and south along the axis of the trough. The coal is reported to contain more impurities toward the southeast and to be divided by a layer of clay. The shale which forms the floor of the Cardiff Coal and the roof of No. 2 Coal is commonly a thin sandstone and pebble conglomerate overlain by a thin black shale or hard underclay which locally merges with the bottom part of the upper bed and makes it bony and unmarketable.

A similar occurrence was encountered in 1958 at Peabody Coal Company Northern Illinois strip mine about 6 miles northeast of Cardiff, where a channel deposit containing coal 57 inches thick, lying only a few feet above the No. 2 Coal, and overlain by several thinner, discontinuous coal seams (fig. 7), was studied by R. M. Kosanke. He visited the site periodically during the mining of the coal from the channel-like deposit and collected samples for palynological studies, both from the strip mine face and from coal test drilling in the area. In a recent study, Peppers (1970) made a detailed palynological correlation based on these samples.

Peppers found that the spores from the coal in the "multiple seam area" studied by Kosanke closely resembled those from the Cardiff Coal in samples collected from drill holes in the area between the strip mine exposure and Cardiff. Peppers (1970) interpreted the Cardiff Coal as having formed in abandoned channels, or small depressions, that contained a flora similar to that of the Lowell Coal but having formed earlier and under somewhat different ecological conditions.



Fig. 7 - Cardiff Coal at strip mine highwall near Clarke City. The floor of the pit is on the top of the No. 2 Coal. The photo was taken near the northern limit of the lenticular coal which rises to the north and pinches out a short distance to the right of the photo. Photo by Clegg(1958).

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DEPOSITIONAL ENVIRONMENTS IN THE FRANCIS CREEK SHALE

Charles W. Shabica
(University of Chicago)

INTRODUCTION

It is generally agreed that the Francis Creek Shale Member of the Carbondale Formation represents a "clastic wedge" thinning, becoming more marine to the west. Weller (1957) considered the Francis Creek Shale to represent the introductory phase of the marine part of a cyclothem in which deposition probably occurred rapidly in very shallow water close to shore. Krumbein (1947) examined the Francis Creek Shale in Fulton County, Illinois. On the basis of areal extent and lithologic properties and associations, he theorized that the shale was deposited in shallow water (possibly marine) just offshore, but close to the source area. Richardson (1956) described the Francis Creek Shale of Grundy and Will counties as a sediment deposited on a delta-like aggrading plain predominantly above sea level, but not far from shore. Wright (1965) mapped the regional sedimentological pattern of the Francis Creek Shale and described it as prodelta silts and muds.

Examination of outcrops and closely spaced cores (as close as one-half mile apart) shows the Francis Creek Shale to be locally variable in thickness, lithology and paleontology (isopach map, Smith, this Guidebook, p. 4).

Recent studies of modern deltas and near-shore marine processes have provided sedimentary and biological features considered characteristic of depositional environments. Based on criteria developed in modern environments, facies in the Francis Creek Shale are seen to range from alluvial to prodeltaic. The purpose of this paper is to discuss several local areas in the Francis Creek Shale in terms of features considered to be environmentally diagnostic.

This paper represents one part of a doctoral thesis in preparation on the sedimentology and paleoecology of the Francis Creek Shale. Financial support was provided by the Field Museum of Natural History through the Center for Graduate Studies and by grants from the National Science Foundation (GB-8266 and GB-5772) to R. G. Johnson and E. S. Richardson, Jr.

DESCRIPTION

The Francis Creek Shale Member of the Carbondale Formation (Moore, et al., 1944) of the Des Moines Series was named for rocks exposed on the banks of Francis Creek, Fulton County, Illinois (Savage, 1927). It crops out, or is encountered, in coal mines or drill cores in a broad belt trending southwest between Grundy and Adams counties, Illinois (Smith, this Guidebook, p. 35). The Francis Creek Shale varies from a gray shale to a gray siltstone and locally contains several elongate sandstone bodies. It rests on the Colchester (No. 2) Coal Member and is variable in thickness, ranging from over 80 feet thick in the northeast to less than 5 feet thick in the southwest. It is not found in the central or southern part of the Illinois Basin.

METHODS OF STUDY

A number of outcrops of the Francis Creek Shale were examined in detail; sections were measured and samples were collected for laboratory study. The author also made use of published and unpublished drill core descriptions and drill cores made available by the Illinois State Geological Survey.

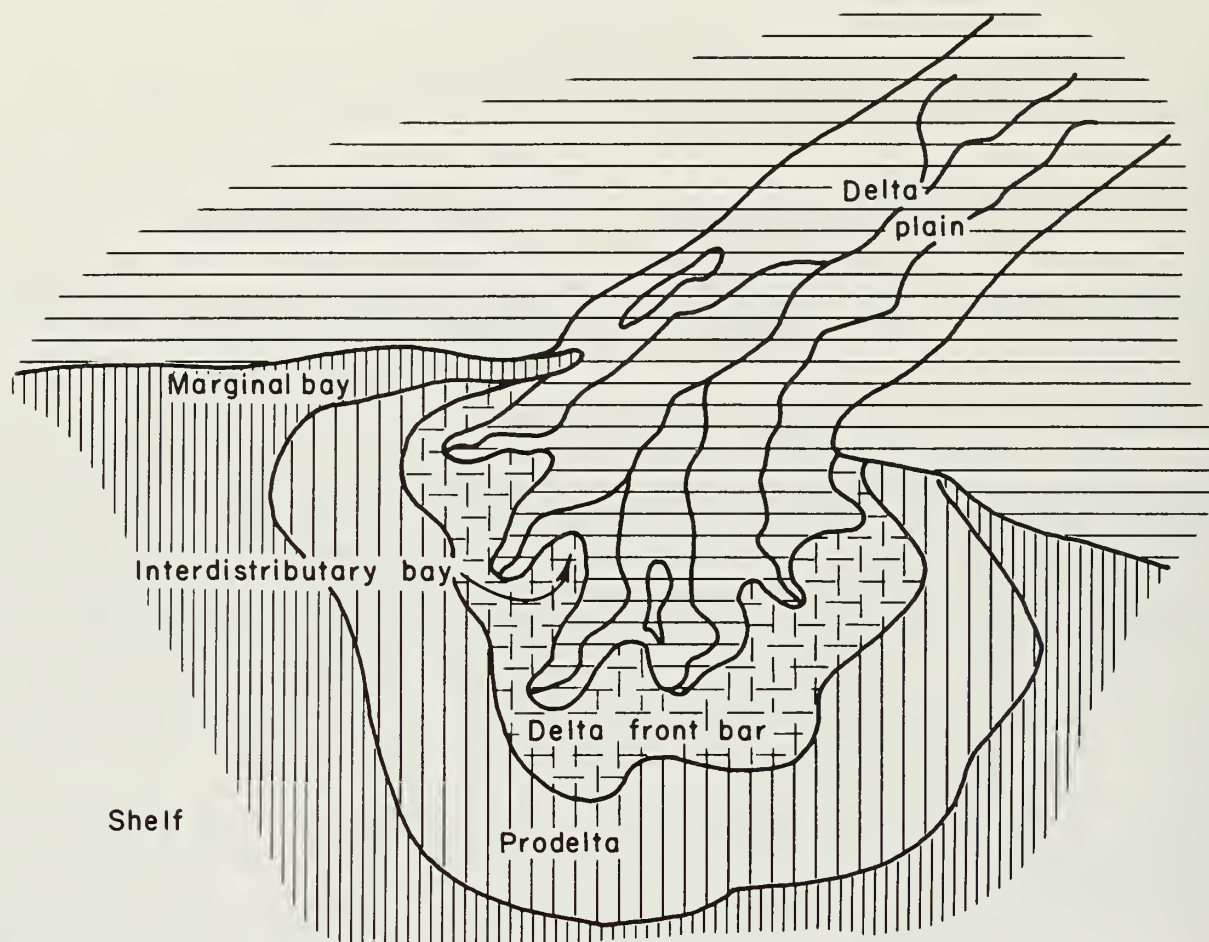


Fig. 1 - Generalized distribution of delta facies. Vertical lines denote areas of marine influence, and horizontal lines, continental influence. Modified after Fisk et al. (1954).

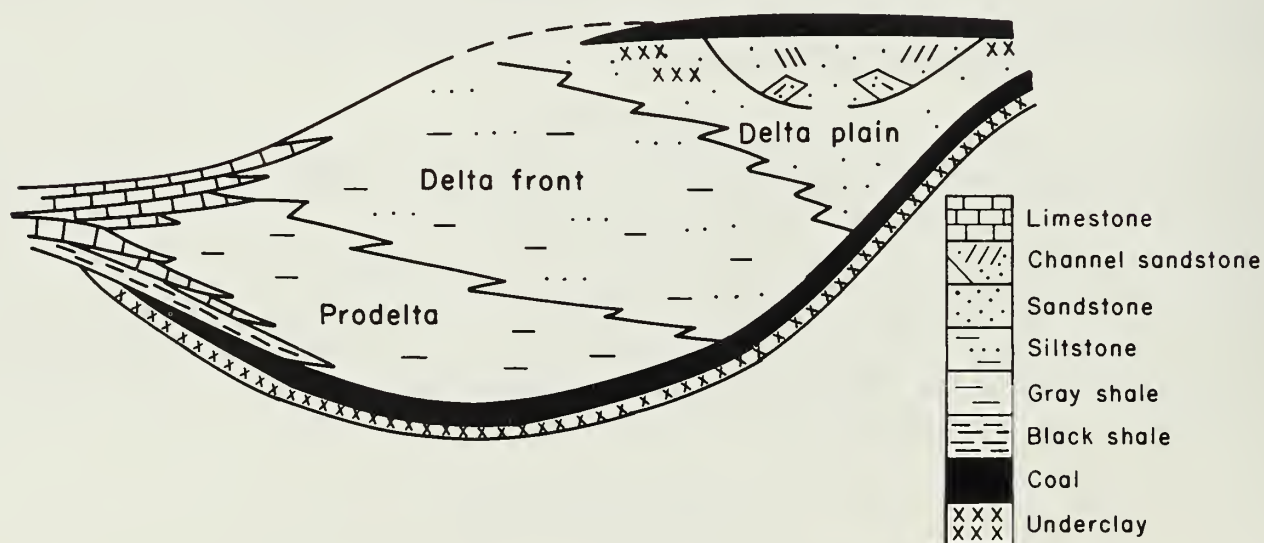


Fig. 2 - Idealized cross section of Pennsylvanian delta facies. Modified after Williams et al. (1964) and Fisher et al. (1969). Vertical scale greatly exaggerated.

Sedimentary Structures:

Extensive literature is available dealing with minor sedimentary structures and their genetic interpretation. Workers have also shown certain suites of sedimentary structures to be characteristic of depositional processes within modern fluvial-deltaic regimes (Moore and Scruton, 1957; Visser, 1965; Coleman and Gagliano, 1965; and others).

Minor sedimentary structures from the Francis Creek Shale have been systematically collected and described. A number of structure types are distinct enough to be used in environmental interpretation, some of which have been observed by the author in modern sediments. All of the structures have been discussed in the literature.

Fossil Evidence:

The Francis Creek Shale has generally been considered as being unfossiliferous except at a few localities including the well-known Mazon Creek area (Will, Kankakee and Grundy counties). This study has revealed an extensive, but not yet fully described marine fauna, in addition to the arthropod-molluscan fauna associated with the Mazon Creek flora.

ENVIRONMENTAL CLASSIFICATION

This study has been limited to local sedimentological and paleoecological problems, as the data now available are sufficient for only the most generalized regional synthesis. The environmental classification applied to the Francis Creek Shale is based mainly on local depositional processes rather than large scale features of a delta complex.

Four major depositional environments will be discussed in relation to the Francis Creek Shale (figs. 1 and 2): prodelta and delta front bar, distributary channel and interdistributary bay, marginal bay, and delta plain.

The following are brief outcrop or core descriptions showing features which are considered characteristic of the depositional environments which are listed in tables 1A and 1B.

PRODELTA AND DELTA FRONT BAR

Figure 3 is a diagrammatic section through the prodelta and delta front bar facies of the Francis Creek Shale. Sediments are primarily silty clays at the base of the shale, grading upward into coarse siltstones and micaceous sandstones. Plant fragments and macerated plant material occur along bedding planes throughout the section. Sedimentary structures include numerous cross-laminations and irregular laminations, slump structures, and parallel laminations.

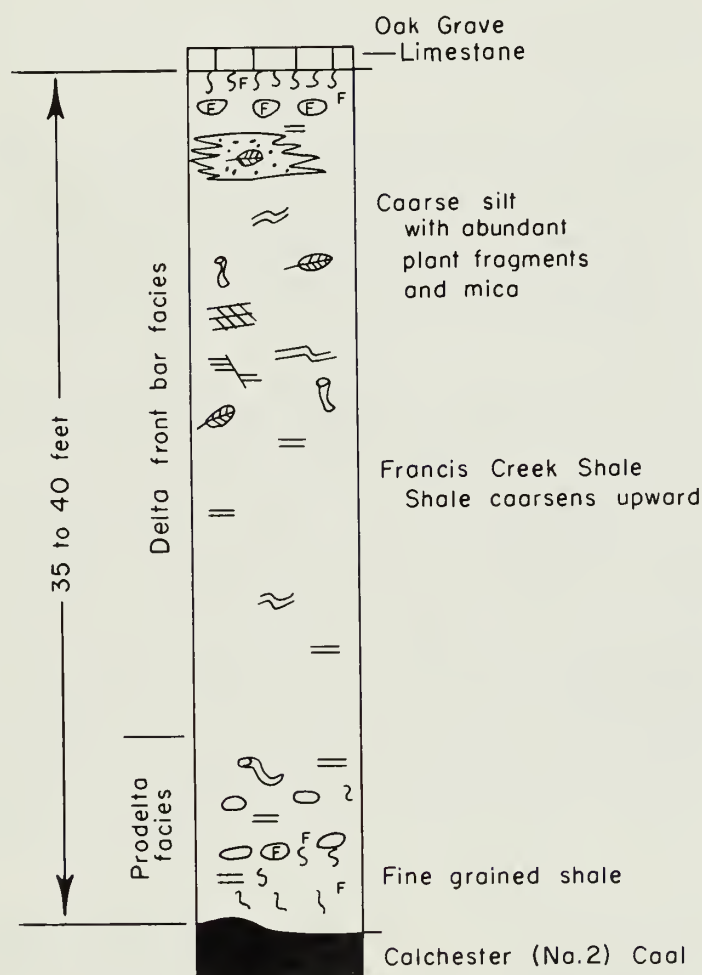


Fig. 3 - Composite sec. from high bluff, SW , NW , sec. 4, T. 5N., R. 3E., Havana quadrangle, Fulton County, Illinois, and high bluff, SW , SW , sec. 12, T. 1N., R. 5W., Augusta quadrangle, Adams County, Illinois (see table 1 for key to symbols).

TABLE 1A — FRANCIS CREEK SHALE DEPOSITIONAL ENVIRONMENTS AND CHARACTERISTIC FEATURES

A = Abundant, P = Present, R = Rare, O = Not Seen














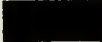
Sedimentary structures	Symbol	Prodelta	Delta front bar	Distributary channel	Inter-distributary bay	Marginal bay	Delta plain
Homogeneous sediments		A				P	
Parallel laminations		P	P	P	A	P	P
Cross laminations						R	A
ripple				A			
wave		P	A	P			
current		P	A	P	P, R		
Plant remains							A
distinct			P	P	at base	A	A
particles		P	A	A	P	P	P
Nodules							
pyrite	P				R	P, R	
siderite	S				A	?	
limestone	L	P	P			P	
Burrows							
small		A	P		R — O	A	
large			P	R	R — O		
Distorted laminations							
slump				at edges	around tree		
recumbent folds				P	R		
Clay inclusions				at base			
<hr/>							
Relative grain size abundance							
sand		O	P	A	O	O	A
silt		P	A	P	A	P	P
clay		A	O	O	P	A	P
<hr/>							
Fossil fauna				O			
individuals	F	P	P		P	A	
breccia		at top				at top	
fragments		P	P				
vagrant benthos					P	P	
sessile benthos		P	P		R	A	
pelagic					A		

TABLE 1B — TYPICAL STRATIGRAPHIC SEQUENCE OF MEMBERS LYING ABOVE AND BELOW THE FRANCIS CREEK SHALE

A = Abundant, P = Present, R = Rare, O = Not Seen

Presence of associated strata	Symbol	Prodelta	Delta front bar	Distributary channel	Inter-distributary bay	Marginal bay	Delta plain
Oak Grove Limestone		P	P	O	O	P	O
Mecca Quarry Shale		O	O	O	O	P	O
Francis Creek Shale		thin	thick	variable	thick	thin	thick, variable
Colchester (No. 2) Coal		thin	thin	P	P	P	thick

Large scale burrows are in most of this section. Small scale burrows and burrow mottling are seen in the fine sediments of the lower 6 feet and at the top of the section where the shale grades into the overlying Oak Grove Limestone. Marine fossils, including Lophophylidium corals, brachiopods, bivalves, and gastropods, are preserved in concretions and in the shale of the lower 6 feet, but fossils in the coarse sediments above are rare. The upper 5 feet of the shale, containing crinoid columnals and bivalves, grades into a crinoidal limestone just above the top of the Francis Creek Shale. No Mecca Quarry Shale is present here.

Widespread layers of reworked shell hash with bioturbated zones extending as much as 1 meter into the sediment below have been observed off the recent Mississippi prodelta (Coleman and Gagliano, 1964). A similar phenomenon is seen at the Francis Creek Shale - Oak Grove Limestone contact where the burrows extend 5 to 10 inches into the underlying Francis Creek Shale. This is interpreted as representing a period of non-deposition in which the remains of benthic organisms accumulated and the rate of biogenic reworking was high compared to the rate of deposition.

The delta front bar and prodelta environments represent the area of active marine deposition in the deltaic system where features common to both normal marine and fluvial environments are seen in association. In the shelf and distal prodelta, where depositional rates and current and wave energy are low, burrow mottling and distinct burrows are the dominant sedimentary structures. In contrast, wave and current reworking and rapid sedimentation near the distributary mouths result in ripple marks and parallel laminations with little bioturbation (Moore and Scruton, 1957). A well developed benthic marine fauna is present in the prodelta environment, but with increased sedimentation rates and current and wave reworking inshore, the fauna becomes sparse. These laterally gradational environments can be distinguished in the fossil delta when found in association.

DISTRIBUTARY CHANNEL AND BAY

Figure 15 in the Road Log of this Guidebook is a diagrammatic section through a suite of rocks ascribed to the distributary channel and bay environments. The section is taken from a highwall exposure of the Francis Creek Shale at the Peabody Coal Company Northern Illinois Mine, Pit 11. This exposure shows 2 facies of the Francis Creek Shale channel sandstones and distributary bay laminated siltstones. Two types of channel development are seen here:

- A. Contemporaneous Channel - These deposits are thin, fine grained sandstones which grade vertically and horizontally into the laminated siltstones. Slump features are found at the edges of the sandstone bodies, and abundant cross-laminations occur

as ripple drift and truncated ripple sets. Fine material preserved on the backslope of the ripples seems to be a result of fine-sediment fallout due to a reduction in velocity of sediment-laden water. In modern situations, approaching the active delta, the distributary channels become wider and shallower and grade into proximal bar, sub-aqueous levee and bay environments. With channel widening, currents diminish and a wide range of sediment sizes is deposited. During low water stages in modern deltas, slumping is a common feature along the channel edges.

- B. Non-contemporaneous Channel - This type is characterized by thick sandstone bodies which cut unconformably into the laminated siltstones of the Francis Creek Shale. Fine grained material is less abundant here than in the contemporaneous channel. Sedimentary structures include wavy laminations, ripple drift, cross laminations, current bedding, shale inclusions (as a basal conglomerate), and recumbent folds. This channel phase may be a delta plain channel associated with either the Francis Creek Shale or a later unit. One channel of this type also contains abundant, large plant and coal clasts.

INTERDISTRIBUTARY BAY

Interdistributary bay sediments are almost entirely laminated siltstones, coarsening upwards and grading laterally into distributary channel sandstones. Small scale current laminations are common.

Except for leaves and stems preserved in the shale just above the coal, nearly all of the fossils occur in siderite concretions and are known collectively as the Mazon Creek biota (Johnson and Richardson, this Guidebook, p. 53). Most of the Mazon Creek fossils are collected as float in mine spoil heaps; thus, little is known of the relationship between the fossils and the enclosing sediment. At Peabody Coal Company, Pit 11, Mazon Creek fossils were recently found preserved in place in the Francis Creek Shale. The fossiliferous concretions occur at several levels in discontinuous and a few laterally persistent concretion layers in the lower part of the Francis Creek Shale. The fossils lie mainly parallel to bedding planes; exceptions are bivalves believed to be of fresh water or euryhaline origin (Ida Thompson, personal communication, 1970). The bivalves are usually preserved with both valves articulated; some were found at the ends of trail-like structures.

Over 80 percent of the fossils collected from the interdistributary bay facies are pelagic or vagrant benthonic forms; sedentary or attached forms other than the bivalves are rare. Parallel laminations or cross-laminations are found in association with the fossiliferous concretions. Evidence of bioturbation is rare and limited to bivalve trails and occasional large scale burrows. Because of the excellent preservation and pelagic nature of the fossils and the low level of bioturbation in the enclosing sediments, it is postulated that the organisms were catastrophically buried in an environment incapable of supporting a benthic fauna for any length of time. Rapid sedimentation is evidenced by upright trees up to 9 feet high rooted in the shale just above the coal (fig. 4). The pithy nature of the trees suggests they would not have been able to stand upright for more than a few years after death (James M. Schopf, personal communication, 1970).

In contrast to the marginal bay environment, depositional rates are higher in the interdistributary bay due to the proximity of distributary channels; thus, animal populations are limited. Conditions ranging from marine through brackish to fresh water may be locally developed, depending on the balance between surface runoff and the ability of channels to carry it to the open sea.

MARGINAL BAY

Figure 5 of the Road Log of this Guidebook shows a mine highwall section through marginal bay facies exposed in the United Electric Coal Companies, Banner Mine. The Francis Creek Shale occurs in elongate, trough-like depressions on a rolling coal topography. These trough deposits have been traced several hundred yards with continued mining operations (Roger B. Nance, personal communication, 1970).

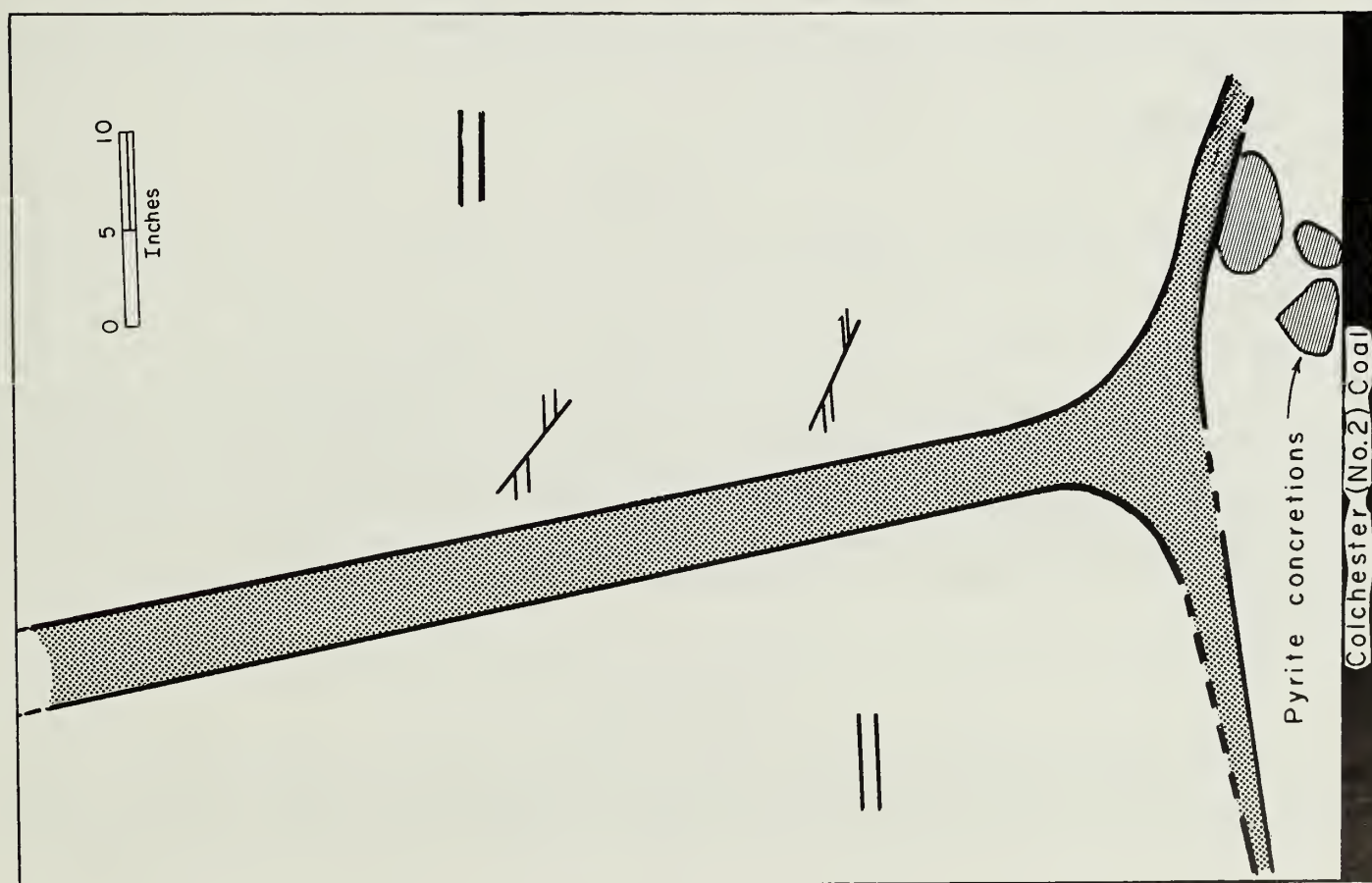
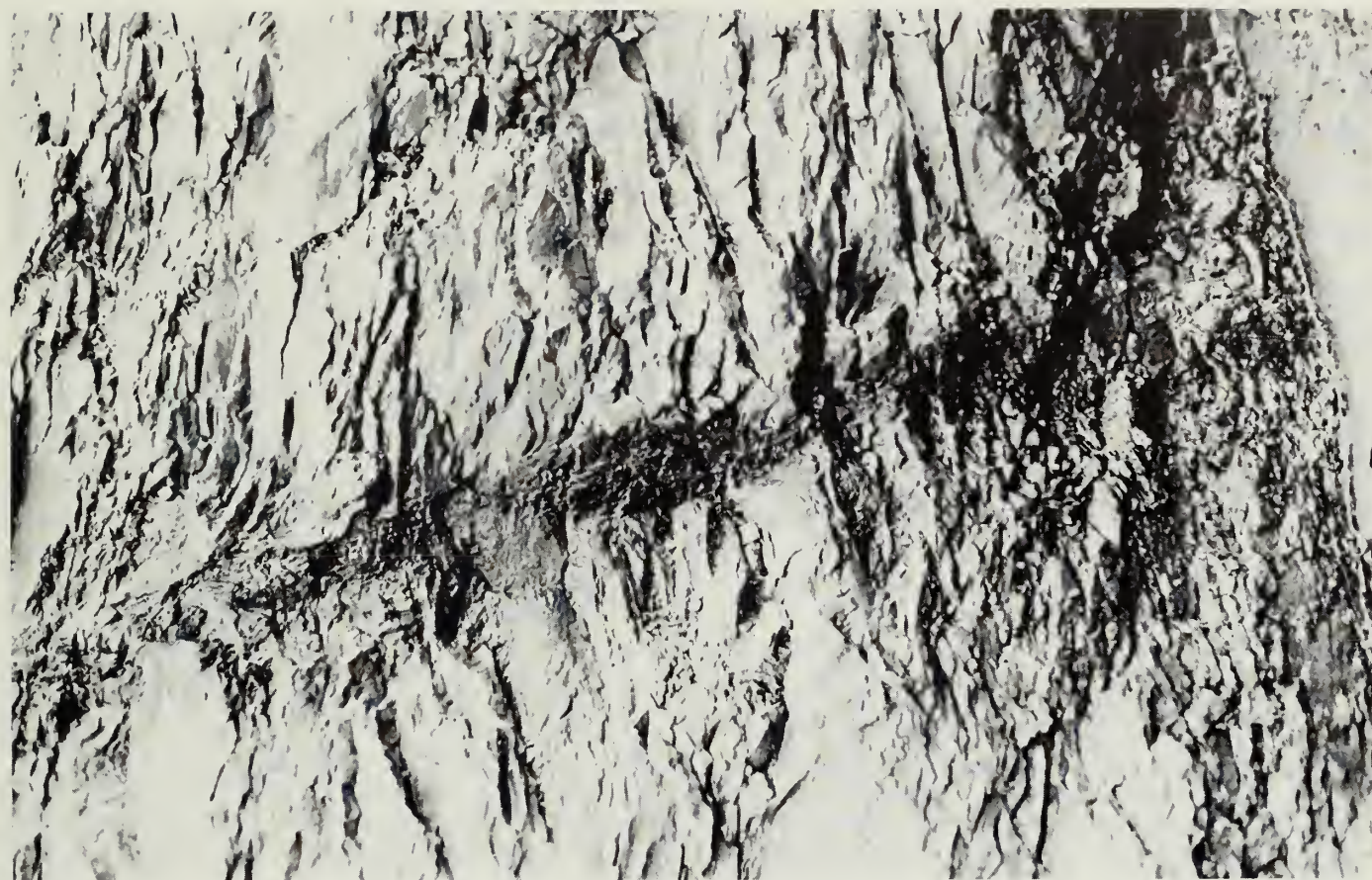


Fig. 4 - Fossil tree exposed at base of Francis Creek Shale, Peabody Coal Co., Plt 11 highwall.

The sediments are gray, slightly silty clay showing little textural or mineralogical variation vertically or laterally; coarse material is noticeably absent. Because of the homogeneous nature of the shale, sedimentary structures are indistinct except in polished section. Parallel and wavy laminations and small-scale burrow mottling are the predominant sedimentary structures, and plant impressions and fragments occur on bedding planes.

The following is a list of the more commonly occurring fossil species of the marginal bay deposits at Banner Mine:

C = common

L = lower part of section

P = present

M = middle

R = rare

U = upper

Fossil fauna	Relative abundance	Stratigraphic position	Comments	
Brachiopoda				
<u>Lingula</u>	C	L	Pioneering marine form	
<u>Mesolobus</u>	C	L, M, U		
<u>Desmoinesia</u>	C	M, U		
<u>Neospirifer</u>	R	U		
<u>Composita</u>	P	U		
<u>Chonetes</u>	P	U		
Bivalvia				
<u>Myalina</u>	C	L, U	Delicate spines unbroken	
Nuculoids	P	L, M, U		
Conodonts				
<u>Idiognathodus</u>	P	U		
Ostracoda				
<u>Healdia</u>	C	U		
<u>Hollinella</u>	P	U		
Gastropoda				
unnamed	P	M		

The marginal bay environment includes areas of relatively low sedimentation rate within the delta, with marine conditions ranging from open to restricted. Generally shallow and elongate, these bodies of water may be partially or completely surrounded by channel levees or, more frequently, swamp. Thus marine faunas living here may range from poorly to well developed. The detrital influx is variable, depending on the distance from distributaries, but is generally low, resulting in thin stratigraphic units. Sedimentary structures are of the types found in modern restricted lagoons or bayous.

DELTA PLAIN

Figure 5 shows 2 sections through the delta plain facies of the Francis Creek Shale. Interpretation is based mainly on core description and is tentative pending further investigation. A number of features not seen in the others occur in this facies. Sediments are predominantly coarse siltstones



The underclays and coals may have developed on subaerial levees and floodplains and in abandoned channels. Absence of marine fossils within the Francis Creek Shale Member and overlying members suggests that this represents the terrestrial part of the delta.

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FAUNA OF THE FRANCIS CREEK SHALE IN THE WILMINGTON AREA

Ralph G. Johnson and Eugene S. Richardson, Jr.
(University of Chicago and Field Museum of Natural History)

INTRODUCTION *

The Mazon Creek faunas, composed of non-marine, marginal marine, and open sea invertebrates and vertebrates, occur in ironstone concretions in the Francis Creek Shale Member of the Carbondale Formation (Pennsylvanian) in northeastern Illinois. Fossils have long been collected from exposures along Mazon Creek and from spoil heaps of strip mines in the vicinity of Braidwood, Illinois. In the mid-nineteenth century, the Mazon Creek flora was described by Lesquereux and others. Terrestrial and fresh-water invertebrates were reported by Meek and Worthen (1860-70), Dana (1864), Packard (1886), and Scudder (1865-95). The most recent papers concerning the fauna of the classical collecting areas are those of Carpenter (1943, 1964), Richardson (1965), Brooks (1962), and Kjellesvig-Waering (1963, 1969).

In recent years, the Peabody Coal Company has opened a strip mine near Essex, Illinois (Pit 11). In this mine and in the long-abandoned MacElvane Pit adjoining it, a fauna dominated by marine invertebrates has been discovered. In the classical Mazon Creek collecting areas, plant fossils outnumber animal fossils by more than 100 to 1. In the new area, animal fossils, most of which are the remains of soft-bodied animals, are as common as plants. For the convenience of reference, the classic fauna, dominated by terrestrial forms, has been designated the "Braidwood concretion fauna," while the marine-dominated assemblage has been referred to as the "Essex concretion fauna" (Johnson and Richardson, 1966).

In 1965 we began an intensive study of the Essex fauna, a joint venture of the Field Museum and the University of Chicago with the support of a grant by the National Science Foundation (GB-5772 and GB-8266). An enormous number of specimens are available, largely due to the work of many amateur collectors in northern Illinois. We would have had only a scanty understanding of the Essex fauna without their help.

Only a few species in the Essex fauna have been described to date. Richardson (1966) has described the very common and curious Tullimonstrum gregarium (plate 4A). Johnson and Richardson (1969) presented a more detailed account of the morphology and zoological affinities of Tullimonstrum, based on examination of over 1000 specimens. Johnson and Richardson (1968a) have described a remarkable coleoid cephalopod, Jeletzkyia douglassae, and jellyfish (1968b) from the Essex locality (plate 4B). Schram (1969) discussed several crustacea and has further studies in press concerning these elements. Zangerl (1969) described an infant shark, and Bardack and Zangerl (1968) discussed the first fossil lamprey in the geologic record. A single crinoid specimen is known (Lane, 1969) which appears to be an immature, epiplanktonic form. Among the undescribed fossils are many polychaete annelids, a holothurian, bivalves, and several animals of unknown affinities.

PRESERVATION

The preservation of the Mazon Creek fossils is exceptional. Aside from a few fossils preserved in areas of low rates of deposition, such as lagoons and a large number of carbonized leaves and stems immediately above the coal, the Mazon Creek fossils are found mostly in siderite concretions. The concretions are a critical factor in the extraordinary preservation, and it seems likely that remains not protected by the formation of a concretion were destroyed. Preservation of the

* Taken in large part from Richardson and Johnson (1970).



Plate 4 - Well preserved fossils from the Mazon Creek fauna with magnifications: A. Tullimonstrum (x 0.8), B. Octomedusa (x 2.5), C. an undescribed insect (x 1.2), D. Acanthotelson (x 1.2).

soft-bodied animals required rapid burial, with consequent inhibition of aerobic decomposition and rapid development of concretions.

Rapid deposition in some parts of the Francis Creek Shale is confirmed by the preservation of upright tree trunks rooted on top of the coal (Shabica, this Guidebook, p. 48). One of the trunks found in the highwall of Pit 11 was at least 3 meters long. With rapid accumulation of sediment under water, animal and plant remains are quickly sealed off from oxygen and scavengers, thus the phase of aerobic decay is brief (Zangerl and Richardson, 1963).

The early formation of certain concretions has been documented by Zangerl et al. (1969) and others. The Mazon Creek concretions probably formed as firm bodies shortly after burial, but before the completion of anaerobic decomposition of the organic remains. The animal formed a firm impression in the enclosing body before biological degradation could destroy its membranous substance. Many of the impressions were made by undecomposed animals still retaining most of their three-dimensional fullness. In these instances, decomposition of the tissue, after creation of the impression, resulted in cavities that were later filled by calcite, sphalerite, kaolin, pyrite or rarely, galena.

Almost all of the Mazon Creek fossils lie parallel to the well developed bedding in the shale. The only exceptions include some pelecypods and polychaetes apparently buried in life attitude. At present there is no adequate theory to account for the formation of concretions. Formation is partly controlled by the fossil, as the outline of the concretion commonly follows the broad outline of the fossil (plate 4A).

Chitin, the principal skeletal constituent of arthropods, is variously preserved in the concretions. The well sclerotized skeleton of crustaceans and millipedes remains as a thin, orange-brown layer, broken into numerous small polygons by post-burial fluid loss. The lightly chitinized skeletons of freshly molted crustaceans and the thin, flexible skeletons of insects, of xiphosurs, and of some arachnids are preserved only as sharp impressions, some of which are covered with a carbonized film.

Bone, dentine, and ganoine are commonly preserved with little or no alteration, though the bones of articulated young amphibians were usually dissolved and replaced by calcite or kaolin. Calcareous skeletal structures, except in the echinoderms, were dissolved after making a firm impression. Holothurian oral rings and crinoid plates remain as crystalline calcite.

All soft-bodied forms, including medusae, young fishes, and polychaetes are more visible by color contrast than by relief. A freshly broken, unweathered concretion is light gray. Against this background, the fossil may be nearly invisible or may show as a lighter gray. Weathering increases the color contrast, and the matrix and fossil darken. In some instances, as in the lamprey, anatomical detail is traced by a darker material.

The largest animals, most of which are less than 10 centimeters in length, are known only from fragmentary remains. Individual specimens differ widely in their state of decomposition and preservation. However, the large number of specimens available for study makes it possible to reconstruct the anatomy of any species in greater detail than is usually possible in paleontology.

DISTRIBUTION

There are several concretion zones visible along the present highwall of the mine at the Essex locality (Peabody Pit 11). As most of the fossils are collected from spoil heaps, we cannot determine the stratigraphic level at which these specimens originally occurred. In various areas of the mine, there are concentrations of particular species. This cluster pattern of distribution may reflect environmental heterogeneity or circumstances in which the area was inhabited for brief periods.

FAUNA

The principal elements of the Essex fauna are given in Table 1. The relative abundance of individuals of major taxa in collections from the Essex and Braidwood faunas is shown in Table 2, and

TABLE 1 - PRINCIPAL MEMBERS OF THE MAZON CREEK FAUNA

TAXA	NO. OF SPECIES	GENERAL HABITAT	TAXA	NO. OF SPECIES	GENERAL HABITAT
COELENTERATA			<u>Anthracaris</u>	1	m, f
<u>Anthracomедusa</u>	1	m*	<u>Belotelson</u>	1	m
<u>Octomedusa</u>	1	m	<u>Anthracophausia</u>	1	m
MOLLUSCA			<u>Mamayocaris</u>	1	m
Bivalvia			<u>Kallidectes</u>	1	m
<u>Aviculopecten</u>	3 (?)	m	<u>Tyrannophontes</u>	1	m
<u>Euchondria</u>	1	m	<u>Dithyrocaris</u>	1	m
<u>Dunbarella</u>	1	m	Other phyllocarids	1	m
Other pectinids	2	m	Merostomata		
<u>Lima</u>	1	m	<u>Euproops</u>	2	m, f
<u>Nuculana</u>	1	m	<u>Paleolimulus</u>	1	m, f
<u>Yoldia</u>	1	m	Eurypterids (<u>Adelophthalmus</u>)	1	f
<u>"Solenomya"</u>	1 (?)	?	<u>Cyclus</u>	1	m (?)
Gastropoda			Arachnida	8	t
Bellerophontids	3	m	Mandibulata		
"Nudibranch"	1	m	Myriopods	24	t
Other gastropods	3	m	Insects	175	t
Cephalopoda			ECHINODERMATA		
<u>Ieletzkyia</u>	1	m	Holothurian	1	m
Goniatite nautiloid	1	m	Crinoid	1	m
Amphineura			CHORDATA		
<u>Helminthochiton</u>	1	m	Fish		
ANNELIDA			<u>Acanthodes</u>	2	m
Polychaetes	15	m	Pleuracanth	1	f
"Leech"	1	?	Cladodont	1	m
TULLIMONSTRUM	1	m	Rhipidistian	1	m
BRACHIOPODA			Coelacanth (<u>Rhabdoderma</u>)	1	m
<u>Lingula</u>	1	m	<u>Palaeoniscoides</u>	3	m, f
<u>Orbiculoides</u>	1	m	Other sharks	4	m
ARTHROPODA			<u>Sagenodus</u>	1	m
Crustacea			Other lungfish (<u>Conchopoma</u>)	1	m
<u>Leia</u>	1	m, f	Lamprey (<u>Mayomyzon</u>)	1	m
<u>Cyzicus</u>	1	m, f	Amphibians		
Ostracodes	2	m, f	<u>Amphibamus</u>	1	f, t
<u>Acanthotelson</u>	1	m, f	<u>Ophiderpeton</u>	1	f, t
<u>Paleocaris</u>	1	m, f	<u>Phlegethontia</u>	1	f, t
			"Blade" (larvae ?)	1	?

*m - marine; f - fresh water; t - terrestrial; m, f - brackish water.

some particularly well preserved fossils from the Essex fauna are illustrated in plates 4 and 5. The Braidwood fauna consists mainly of terrestrial and freshwater forms. Elements of this fauna occur with the dominant marine Essex fauna.

Table 2 - Relative abundance of major taxa in collections from the Essex and Braidwood faunas. The Essex collection consists of 3214 specimens. The most abundant element, a medusiform organism, has been left out of the table; it constitutes about 50 percent of the Essex fauna. The Braidwood collection consists of 1213 specimens.

TAXA	ESSEX FAUNA	BRAIDWOOD FAUNA
Coelenterata	2.3 %	0 %
Mollusca	15.7	18.4
Polychaetes & other vermes	20.8	1.8
Arthropoda	44.9	79.5
Echinodermata	5.0	0
<u>Tullimonstrum</u>	9.9	0
Chordata	1.2	0.3
	99.8 %	100.0%

At the Essex locality, Pit 11, about 25 percent of the concretions contain recognizable fossils. Of these, animal and plant fossils are about equal in number. In the Braidwood areas, plants outnumber animals more than 100 to 1. We find that about one-third of the fossils are sufficiently well preserved to be worth adding to the Museum's collections.

The Braidwood fauna is dominated by xiphosurans, the eumalacostracans Acanthotelson and Palaeocaris, and several species of fresh-water bivalves. Although insects are rare, they have made important contributions to knowledge of the early history of the group. The Braidwood fauna is known from many localities in Grundy and Will counties in Illinois, from western Indiana, and possibly, from Oklahoma (Okmulgee County).

The Essex fauna is dominated by marine forms. However, the most common fossil is a medusiform organism of unknown affinities. This fossil, known to collectors as the "blob," generally constitutes about 50 percent of the fauna, but at some places in Pit 11 constitutes as high as 80 percent. Belotelson, Tullimonstrum, an undetermined bivalve, and a polychaete are among the most common animals. From the standpoint of major taxa, crustacea are the most abundantly represented, with the polychaetes ranking second, much lower. The Essex fauna is known primarily from the Pit 11 locality but elements have recently been discovered elsewhere.

PALEOECOLOGY

Richardson (1956) interpreted the life environment of the Braidwood fauna as a swamp forest. The environment of deposition, however, may have been in brackish waters, since a few marine and brackish water species are present. The simplest explanation is that the Braidwood fauna developed in the more fresh water and terrestrial parts of a deltaic forest and was transported after death into more brackish and marine waters. Transport, however, was minimal, with no fragmentation of delicate skeletons.

The Essex fauna presents greater difficulties. The most common fossils appear to be of pelagic and nektonic animals. The polychaetes are infaunal, errant forms. There is practically no evidence

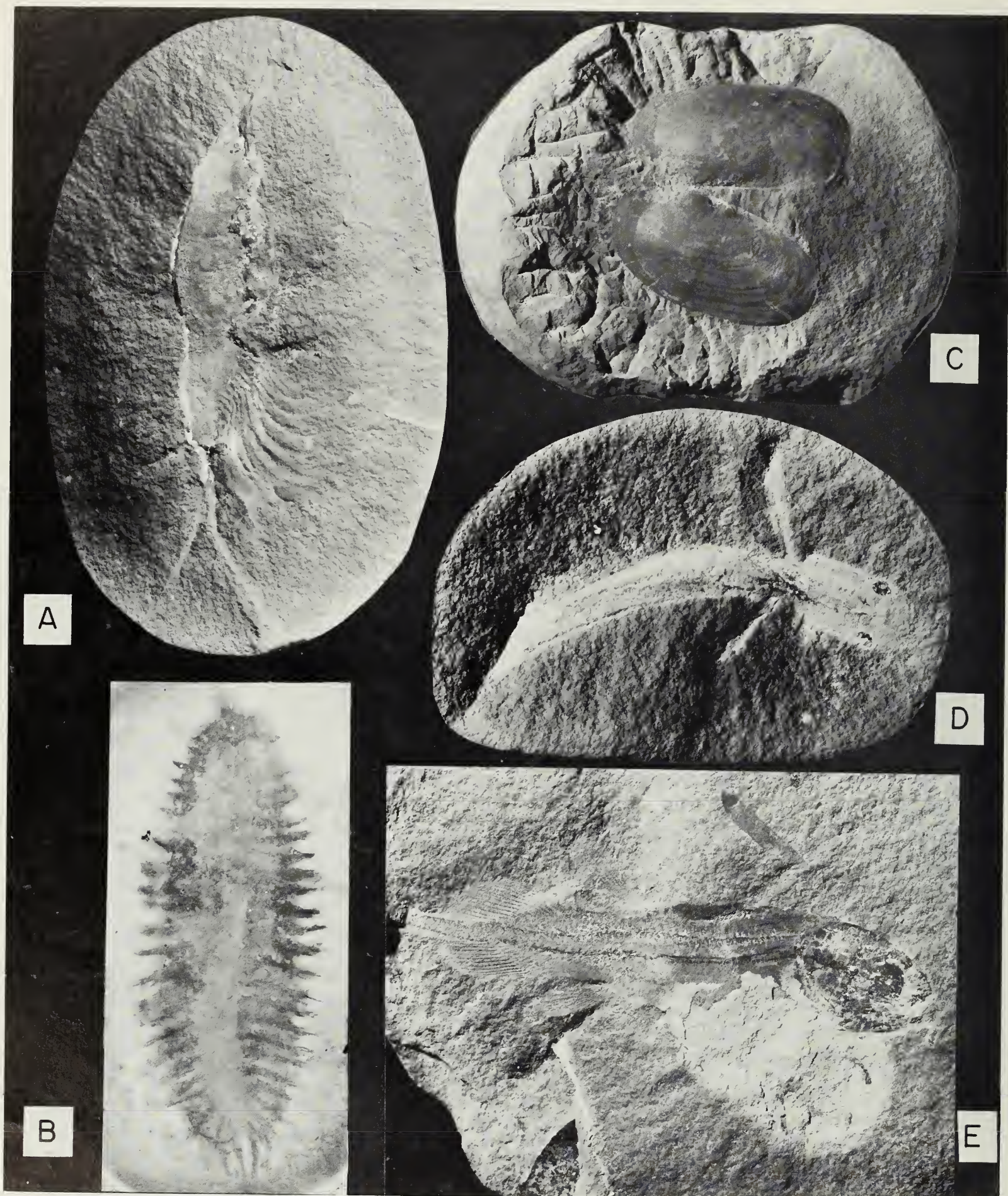


Plate 5 - Well preserved fossils from the Essex fauna with magnifications: A. Kallidectes (x 1.2), B. an undescribed polychaete (x 1.6), C. a common bivalve (x 1.2), D. the "blade," possibly a larval amphibian (x 1.2), E. Rhabdodermis, a coelacanth (x 1.2).

of biogenic reworking of the sediment. The absence of articulate brachiopods and corals and the rarity of snails, cephalopods and crinoids are peculiar features. The geologic evidence indicates that the environment of deposition probably was a sub-aqueous, interchannel flood plain slightly above sea level (Shabica, this Guidebook, p.51).

The clustered pattern of fossil distribution on the spoil heaps could indicate that the area was inhabited for only brief periods. The fact that the concretions occur in thin zones at several levels may indicate several brief marine incursions into areas that were covered with fresher waters most of the time. This hypothesis would account for the mixed assemblage dominated by planktonic and nektonic marine animals, and the virtual absence of biogenic structures.

Today marine waters are commonly moved inland by storm surges. Gale force winds are capable of locally raising sea level 5 to 10 feet. The coincidence of winds and low pressure can produce much higher water levels. Considering the very small slope which must have existed on the lower delta plain, inland movement of marine waters by storms must have commonly occurred. After a storm, increased discharge from the distributaries would introduce fresh water and terrestrial remains to the site of deposition. Flooding, sediment-laden waters would rapidly engulf and bury the marine animals swept inshore.

The storm surge hypothesis is consistent with all of the evidence presently available. It appears to be a syllogism of paleontology that all instances of extraordinary preservation are associated with extraordinary environments and events. There can be little doubt that storms were important geologic agents in ancient epicontinental seas, and more evidence of their passage is recognized in the remains of low lying border lands.

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A COMPARISON OF THE FLORAS OF THE COLCHESTER
(NO. 2) COAL AND FRANCIS CREEK SHALE

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INTRODUCTION

Abundant data from spore studies of the Colchester (No. 2) Coal Member and from investigations of plant compressions in the Francis Creek Shale provide an opportunity to compare the flora of the coal with that of the overlying shale in the northeastern part of the Illinois Basin. As both floras were investigated by different methods and since different systems of form genera were used, it is first necessary to review the plant taxa found in the 2 facies and to arrange them according to major plant groups. Paleoenvironmental interpretations of Pennsylvanian floras are rare and widely scattered in the literature; therefore, some of the research on fossil spores and plant assemblages from other strata is discussed in this report. Finally, the report presents an interpretation of paleoecological conditions that existed during deposition of peat and mud, which eventually formed the No. 2 Coal and Francis Creek Shale.

SPORE FLORA OF THE COLCHESTER (NO. 2) COAL

The Colchester (No. 2) Coal Member of the Carbondale Formation and its equivalents have been the subject of more published palynological studies than any other coal in North America. Kosanke (1950) was the first to report on the miospores in the No. 2 Coal from several localities in Illinois and remarked on the diversified flora that is represented. Winslow's (1959) comprehensive work on the large spores and megaspores from most Illinois coals included a discussion of the No. 2 Coal. The small spore genera from 3 samples of Colchester Coal (IIIA) of Indiana (correlative to No. 2 Coal of Illinois) were recorded by Guennel (1952), and Wilson and Hoffmeister (1956) noted the presence of 48 species of spores from 9 localities of the Croweburg Coal in northeastern Oklahoma. Denton (1957), Habib (1966), and Gray (1967) carried out palynologic investigations of the Lower Kittanning Coal of Ohio and Pennsylvania (thought to be equivalent to the No. 2 Coal). Habib listed about 140 species from 15 sample sites. Meyers (1967) presented data on the distribution of the plant microfossils in 2-inch increment samples of the Henryetta Coal in the central part of eastern Oklahoma. Peppers (1970) differentiated 164 taxa from 50 samples taken from 23 localities in Illinois and showed some lateral variations in spore distribution.

Composition of Spore Assemblages in the No. 2 Coal

The spore assemblages in the No. 2 Coal are rich and varied. Although differences in the overall spore composition occur from place to place, the No. 2 Coal can generally be differentiated from other coals and correlated throughout the Basin.

Lycospora (54 to 66 percent) is the dominant small spore genus in the No. 2 Coal. The second and third most commonly encountered taxa are Laevigatosporites (mostly L. minutus and L. globosus) and Crassispora, which make up 15 to 25 percent and 6 to 11 percent respectively. Florinites (2 to 5 percent) is more abundant in the No. 2 Coal than in any other coal in the Carbondale Formation.

Calamospora, Punctatisporites, Thymospora, and Triquitrites make up most of the remaining spore population. Triletes is dominant (Winslow, 1959) in the large spore assemblage, and Monoletes is usually common in the No. 2 Coal of northern Illinois, except in one sample from Grundy County.

In the area of the Ancona-Garfield structure, which lies along the axis of the La Salle Anticlinal Belt in southern La Salle County (fig. 1), the spore content of the No. 2 Coal differs from that of other parts of northeastern Illinois (table 1). There, the frequency of Laevigatosporites and Crassispora increases considerably so that they attain up to 47 and 25 percent respectively, at the expense of Lycospora. In the Cardiff area of northwestern Kankakee County, where an unusually thick channel-deposited coal occurs a few feet above, or is in contact with the No. 2 Coal, the proportion of Lycospora to Laevigatosporites is also reduced.

Paleobotanical affinities of the isolated spores are found in numerous papers that describe fossil fructifications with spores in situ. Potonié's (1962) monograph is a valuable reference for those studies published before 1962. The following is a list of the spore genera identified from the No. 2 Coal, arranged according to their paleobotanical affinities.

LYCOPSIDA

Crassispora
Lycospora
Densosporites
Cristatisporites
Vallatisporites
Cirratriradites
Endosporites
Triletes

SPHENOPSIDA

Elaeterites
Calamospora (in part)
Vestispora (in part)
Laevigatosporites (only large species)

NOEGGERATHIALES*

Calamospora (in part)
Cyclogranisporites (in part)
Vestispora (possibly)

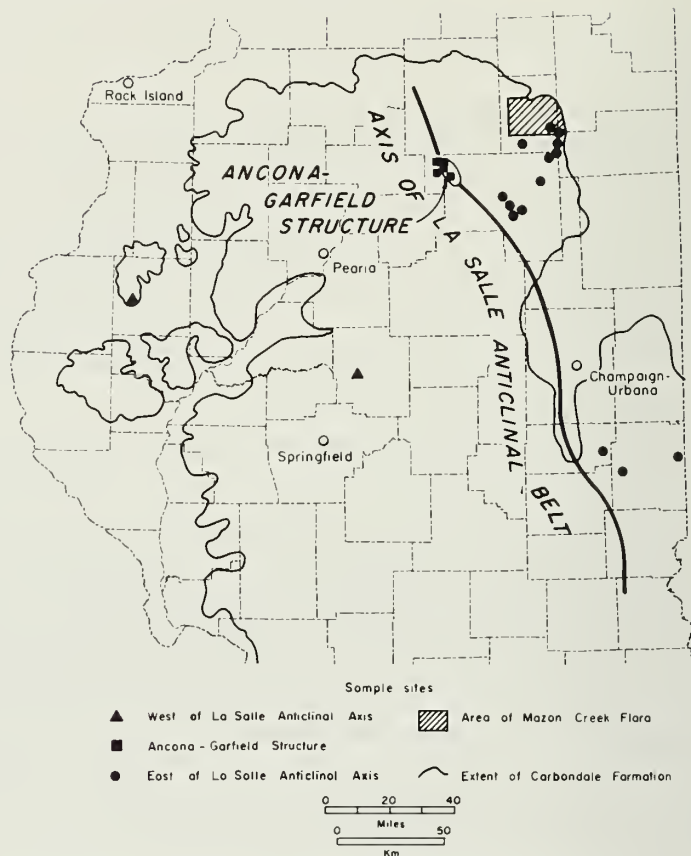


Fig. 1 - Area of Mazon Creek flora and sites from which the Colchester (No. 2) Coal has been sampled for spore analysis, adapted from Peppers (1970).

FILICALES

Leiotriletes
Granulatisporites
Verrucosisporites
Lophotriletes
Raistrickia
Convolutispora
Camptotriletes
Savitrissporites
Thymospora
Torispora
Punctatisporites
Cyclogranisporites (in part)
Laevigatosporites (only small species)
Microreticulatisporites (possibly Filicales)
Triquitrites (possibly Filicales)
Mooreisporites (possibly Filicales)

* Probably not significant in the coal-forming swamp because Noeggerathiales is thought to be in the upland flora.

PTERIDOSPEMALES	<u>Spackmanites</u>
<u>Vesicaspora</u>	<u>Maculatasporites</u>
<u>Florinites</u> (in part)	<u>Dictyotrilletes</u>
<u>Monoletes</u> (in part)	<u>Reticulatisporites</u>
	<u>Knoxisporites</u>
CORDAITES	<u>Indospora</u>
<u>Florinites</u> (in part)	<u>Grumosisporites</u>
	<u>Cadiospora</u>
UNKNOWN	<u>Reinschospora</u>
<u>Converrucosisporites</u>	<u>Tuberculatosporites</u>
<u>Schopfites</u>	<u>Wilsonites</u>
<u>Kewaneesporites</u>	<u>Perotrilletes</u>
<u>Anapiculatisporites</u>	<u>Hymenospora</u>
<u>Pustulatisporites</u>	<u>Paleospora</u>
<u>Apiculatisporis</u>	<u>Alatisporites</u>
<u>Acanthotrilletes</u>	

TABLE 1 - AVERAGE ABUNDANCE OF SMALL SPORE TAXA IN THE COLCHESTER (NO. 2) COAL

Plant groups	Spores	West and east of Ancona-Garfield structure (%)	On Ancona- Garfield structure (%)
Lycopods	<u>Lycospora</u>	54-66	34
	<u>Crassispora</u>	5-11	12
Ferns	<u>Laevigatosporites</u>	12-22	35
	<u>Punctatisporites</u>	2-4	2
	<u>Thymospora</u>	1	5
Sphenopsids	<u>Laevigatosporites</u>	3	2
	<u>Calamospora</u>	2	2
Pteridosperms	<u>Florinites</u>	2-3	2-3
	<u>Monoletes</u>		
Cordaites	<u>Florinites</u>	2-5	2-5
Other spores		1	3

In the No. 2 Coal, spores having their affinity with arborescent lycopods account for 59 to 77 percent of the assemblage. The second and third most commonly encountered spores are those derived from the Filicales (15 to 25 percent) and sphenopsids (about 3 to 8 percent), which are represented by Calamospora and the larger species of Laevigatosporites. Five percent or less of the coal flora consists of the gymnospermic Cordaitales and pteridosperms, most of which are probably Cordaites. It is difficult to assess the proportion of the pteridospermic Monoletes pollen present because the small and large spore assemblages, including megaspores, are separated and treated differently during preparation for spore studies. Pteridosperms might have been more common than indicated in table 1. However, evidence from the coal ball flora (Pfefferkorn, unpublished data) also points to their rare occurrence in the peat flora.

Spore Succession in Coals

Since correlation of coals has been the principal objective of most of the palynologic studies in Illinois, sampling of coals in relatively large increments, such as lower, middle, and upper benches, has been made. However, trends in spore succession in the No. 2 Coal have been observed from these studies. Kosanke (1950) mentioned that Schopfites is more abundant in the lower portion of the coal, while Alatisporites and Calamospora are more common in the upper portions, but numerically these genera are not very significant. Generally there is a decrease of Lycospora and an increase in Laevigatosporites, especially L. globosus, from the bottom or middle of the coal to the top.

Paleoecologic interpretations of coal deposition based on spore studies have been suggested by several workers (Neves, 1958; Peppers, 1964, 1970; Marshall and Smith, 1965; Habib, 1966; Habib, Reigel, and Spackman, 1966; Habib and Groth, 1967; and Clapham, 1970), who have traced the succession of spore assemblages within Carboniferous coals or in coals and associated strata. Other investigations (A. H. V. Smith, 1957, 1964, and 1964; Butterworth, 1964; Alpern, Liabeuf, and Navale, 1964; Hacquebard, Cameron, and Donaldson, 1964; and Habib, 1968) have shown the relation between petrographic and palynologic constituents in coal, but studies of this kind have not yet been made on any coals in the Illinois Basin. A comparison of the floral succession of the No. 2 Coal and Francis Creek Shale with similar investigations in other areas is also hindered by the fact that the No. 2 Coal lies above the range of significant numbers of Densosporites. Most other studies have been made on older strata where Densosporites (from lycopods) plays a significant part in the ecology of the peat swamp.

A decrease in abundance of Lycospora and an increase in small species of Laevigatosporites, (including L. globosus) from the bottom toward the top of the coal, as occurs in the No. 2 Coal, has also been noted by A. H. V. Smith (1957, 1964, and 1964) in some Carboniferous coals in England; by Hacquebard, Cameron, and Donaldson (1964) in the Sydney Coal in Nova Scotia; and by Habib (1966) and Habib and others (1966) in the Lower Kittanning Coal of Pennsylvania. The coals investigated by Smith and Habib, however, are characterized by a significant increase of Densosporites towards the top of the coal. Smith (1957) found that if peat development had not been interrupted, there was another Lycospora phase above the Densosporites phase. Habib (1966) observed the Densosporites zone only beneath marine shale in western Pennsylvania, but as in the No. 2 Coal of northeastern Illinois, he reported (1968) that Laevigatosporites globosus and Punctatisporites obliquus were the dominant species in the upper part of the Upper Freeport Coal where it is overlain by fresh water deposits.

Hacquebard, Cameron, and Donaldson (1964) traced the lateral development of the Sydney Coal through fluviatile, forested peat bog, open moor, and lacustrine environments. In 1957, Smith maintained that the position of the water table during vegetal growth was the controlling factor in the spore succession in coals of Yorkshire, England, and that in the early stages the arborescent lycopods were growing in shallow water where decomposition was anaerobic. As the water became shallower, plants bearing Laevigatosporites (Filicales and Sphenophyllales) were more common, and when the surface of the peat was no longer submerged, but still wet, the Densosporites phase developed. In 1964, however, Smith considered that changes in climate interfered with the normal succession and were responsible for widespread lateral changes in composition of spore assemblages.

According to Habib (1966); Habib, Reigel, and Spackman (1966); and Habib and Groth (1967), arborescent lycopods grew along the margin of the coal swamp at the beginning of peat accumulation of the Lower Kittanning Coal. They were replaced by the Densosporites and Laevigatosporites globosus - Punctatisporites obliquus assemblages toward the center of the basin where the water table was higher and the water more brackish or marine, as indicated by the overlying shales. Although Chaloner and Muir (1968) pointed out the effect of different source areas, movement of shoreline, and changes in sea level on the spore population in coal, they emphasized the importance of climate, supporting Smith's interpretation. Chaloner (1968) compared studies on Pennsylvanian rocks with unpublished data of Muir on spores from British cyclic Jurassic and Cretaceous rocks. Conifer pollen, which responds to fluctuations in climate, was found most frequently in marine shales and in sandstone; whereas, they decrease in abundance in nonmarine rocks and coal.

Clapham (1970) investigated a marine section in the Flowerpot Formation (Permian) of Oklahoma. He found spores of a typical upland flora (mainly conifers) in most of the beds. Only one layer contained spores of a marsh or swamp flora (ferns, cycadophytes, and conifers). According to sedimentological features, this layer indicates a regressive facies.

COMPRESSION FLORA OF THE FRANCIS CREEK SHALE

The well preserved and diverse Mazon Creek compression flora found in concretions of the overlying Francis Creek Shale Member has also been the source of numerous publications. Many of these concretions are found in private collections and museums throughout the world. The flora of the Francis Creek Shale is often called the "Mazon Creek Flora" even though most specimens found today are derived some distance from Mazon Creek. Langford (1958 and 1963), for instance, applied the expression "Wilmington Coal Flora" and Noé (1925) applied the local names Braidwood, Morris, and Coal City to the fauna. For purposes of communication, the term "Mazon Creek Flora" can be applied to all floras collected from the Francis Creek Shale in northeastern Illinois as the general character is the same at all locations. There are, however, minor differences in the floras from different locations which are important for paleogeographical interpretations.

The plant fossils at Mazon Creek were discovered in the middle of the last century. They received special attention because they were attractive and could be collected in large numbers. The nodules normally split along the plane of the fossil, and the shape of the nodule roughly corresponds to that of the fossil. The fossils are not always in one plane but are naturally curved due to the early and rapid formation of the nodules (Johnson and Richardson, this Guidebook, p. 55), resulting in exceptional preservation.

The specimens found in the last century were described in part by Lesquereux (1866, 1870, 1880, 1884) and later by Sellards (1902, 1903). At least one report was published in Italy (Peola, 1907). While underground and strip mining were active in the 1930's, several large collections were made from the large number of fossils exposed. The most outstanding is the Langford collection, which is now housed in the Field Museum of Natural History (which has the largest part of the collection), the Illinois State Museum, and the U. S. National Museum. Noé (1925) discussed part of the flora in a well illustrated report, and one of his students, Janssen (1940, 1946), published several papers on the flora. Several paleobotanists found new forms, mainly fructifications, from museum specimens (Darrah, 1936, 1938; Arnold, 1938; Andrews and Mamay, 1948; Kosanke, 1955; Chaloner, 1956; Delevoryas, 1964; Taylor, 1967). A short report on a special collection made by 2 amateur collectors, Carrs and Daniels, was given by Stewart (1950).

Langford (1958, 1963) was the first to undertake a monographic treatment of the flora. Even though his 2 well illustrated books were mainly written for private collectors, they have been cited in recent scientific monographs. If the limitations of Langford's books in nomenclature and taxonomy are kept in mind, they are the best guides to the flora that exist. A more recent monograph that includes the Mazon Creek Flora has been published by Darrah (1970), in which many special aspects of the flora were described for the first time. The Mazon Creek Flora has been mentioned in numerous other papers, especially those that consider biostratigraphic correlations and floral reconstruction.

Composition of the Mazon Creek Flora

The Mazon Creek Flora is the richest known flora of Paleozoic age in North America, both in the number of species and specimens. The list of generic names provided below shows which genera are found and how they are systematically grouped. Form genera and organ genera are indicated, as well as the correlation of sterile foliage with organ genus of fertile foliage. This should eliminate the confusion produced by Langford (1958, 1963) who applied organ genera names of fructifications to sterile foliage.

LYCOPSIDS (Lycopodophyta, Club mosses)

Lepidodendron
Lepidophloios (bark of trees; these names are
Sigillaria generally applied to the entire
Asolanus plant)
Omphalophloios

Lepidophylloides (formerly Lepidophyllum) (leaf)
Lepidostrobohyllum (leaf on cone)
Lepidostrobus (cone with microspores)
Lepidocarpon (cone with megaspores)
Sigillariostrobus (cone)
Sporangioostrobus (cone)
Stigmaria (root)
Ulodendron (branch scars)

SPHENOPSIDS (Arthrophyta, Articulata, Equisetinae, Calamitacea, horsetails)

Calamites (pith-cast of the stem)
Annularia (whorl of leaves)
Asterophyllites (whorl of leaves)
Calamostachys (cone)
Palaeostachya (cone)
Macrostachya (cone)

Sphenophyllum (leaf whorls on stem)
Sphenophyllostachys (cone)
Bowmannites (cone)

FILICINAE (Pterophyta, ferns)

Marattiales (tree ferns)

Pecopteris (sterile foliage, form genus)
Asterotheca (pecopterid)
Acithec (pecopterid) (fertile foliage, organ genera)
Ptychocarpus (pecopterid)
Radstockia

Psaronius (stem, if found, petrified in coal balls)

Megaphyton (stem, if found, as compression)
Caulopteris

Aphlebia (part of the genus, irregular basal pinnules)

Other ferns

Alloiopteris
Sphenopteris (part of the genus) (sterile foliage, form genera)
Rhodea (?)
Aphlebia (part of the genus)

<u>Dactylothea</u> (pecopterid)	
<u>Senftenbergia</u> (pecopterid)	
<u>Oligocarpia</u> (sphenopterid)	(fertile foliage, organ genera)
<u>Renaultia</u> (sphenopterid)	
<u>Hymenotheca</u> (sphenopterid)	
<u>Corynepteris</u> (alloiopterid)	
<u>Crossotheca</u> (pecopterid to sphenopterid)	fertile foliage genera which
<u>Myriothea</u> (sphenopterid)	might be ferns but have been
<u>Zeilleria</u> (sphenopterid)	attributed to the seed-ferns
	by some authors

PTERIDOSPERMS (Cycadofilicales, seed-ferns)

<u>Neuropteris</u>	
<u>Linopteris</u>	
<u>Cyclopteris</u>	
<u>Odontopteris</u>	(foliage, form genera, often
<u>Alethopteris</u>	being equivalent to natural
<u>Desmopteris</u>	groups)
<u>Mariopteris</u>	
<u>Sphenopteris</u> (part of the genus)	
<u>Diplothemema</u>	
<u>Codonothea</u>	
<u>Whittleseya</u>	
<u>Schopfi theca</u>	(male fructifications)
<u>Dictyothalamus</u> (so called <u>Mariopteris</u> buds)	
<u>Dolerotheca</u> (?) (called <u>Plinthiothea</u> by Langford)	
<u>Trigonocarpus</u>	
<u>Holcospermum</u>	
<u>Samaropsis</u>	
<u>Codonospermum</u>	(seeds)
<u>Carpolithus</u>	
<u>Neuropterocarpus</u>	
<u>Perispermum</u>	

CORDAITES

<u>Cordaitea</u> (leaves and whole plant)
<u>Artisia</u> (pith cast of the stem)
<u>Cordaicladus</u> (leaf scar)
<u>Cordaianthus</u> (male fructification)
<u>Cordaicarpus</u> (seed)

INCERTAE SEDIS (natural affinity not known)

<u>Schopfia</u>

The assignment of form-genera to natural groups usually can be made without difficulty. The only genera which occur in different natural groups, Sphenopteris, Aphlebia, Crossotheca, Myriothea, and Zeilleria are relatively rare and do not drastically alter the statistical analysis of an assemblage.

Statistical counts of the Mazon Creek Flora that have been made by Janssen (1946), Stewart (1950), and Darrah (1970) are shown in tables 2 and 3. Janssen (1946) used about 440 nodules all

smaller than 4.5 centimeters, so he excluded many forms which had not been broken apart before deposition. Stewart (1950) counted 2 collections (Carrs and Daniels, both now at the University of Illinois) and based his count on approximately 3600 specimens. Darrah (1970) included only the most common species and gave percentages only for groups of 4 or 5 species. The last column (this report) lists the major plant groups of about 360 specimens in the Illinois State Geological Survey collection.

TABLE 2 - COMPARISON IN DECREASING ABUNDANCE OF DIFFERENT GROUPS OF PLANTS FROM THE FRANCIS CREEK SHALE IN DIFFERENT COLLECTIONS

Janssen (1946)	Stewart (1950)	Darrah (1970)	ISGS (this report, 1970)
Pteridosperms	Ferns	Pteridosperms	Pteridosperms
Ferns	Pteridosperms	Ferns	Ferns
Sphenopsids	Sphenopsids	Sphenopsids	Sphenopsids
Lycopods	Lycopods	(?)	Lycopods
Cordaitea	Cordaitea	(?)	Cordaitea

The order of decreasing abundance of the groups is the same in all the counts except for the reversal in proportions of ferns and pteridosperms in Stewart's tabulation. As this collection was brought together by 2 local collectors (Carrs and Daniels) near Morris, the difference may reflect a regional difference.

Darrah (1970) noted gigantism, especially in the pteridosperms. In the Carrs and Daniels collection this is apparent in Neuropteris scheuchzeri (or, as Darrah terms the large form, N. decipiens). Besides extremely large specimens, both normal and small sized specimens occur. Ideal growing conditions and a minimum of selection during transportation could account for this size range.

Paleoecological Interpretations of Compression Floras

Paleoecological differences in floras of the same age have been studied by Gothan and Gimm, 1930; D. White, 1931; Daber, 1959; Havlena, 1960 and 1961; Cridland and Morris, 1963, and others. Studies were focused on Permian and upper or lowermost Pennsylvanian plant fossils. No attempt has been made, as far as we know, to use data from both spores and compression fossils. Gothan and Gimm (1930) found 2 distinct floras in the lower Permian of Thuringia: one, immediately overlying the coal seam, is characterized by pectopterids (ferns), Calamites (sphenopsids), and pteridosperms; the other flora, representing a dryer habitat, is the Callipteris - Walchia - association (pteridosperms, sphenopsids and conifers, including Cordaitea). A mixing of the 2 floras was also reported from some localities. Cridland and Morris (1963) found upper Pennsylvanian floras in Kansas and concluded that the upland vegetation was represented by Dichophyllum, Taeniopteris, and Walchia. The swamp flora consisted of Cordaitea, Calamites, Sigillaria, ferns, and pteridosperms.

Cordaitea has been defined both as a swamp plant and as an upland plant. Wartmann (1969) offered a solution to this problem by interpreting Cordaitea as a physiologic "xerophyte," which is able to live in dry areas as well as in swamps, under brackish or saline conditions, and where there is a nitrogen deficiency.

Daber (1959) found 2 floras of similar age in the Dinantian, and Havlena (1961) also found two in the Namurian. The floras have been designated seam-forming ("flosformend" or "flosnah") and those distant from the seam ("flosfern" or "flosfremd"). The seam-forming flora occurs only in the immediately overlying shale and consists of large specimens. At some vertical distance from the seam, plant fragments occur in the shale and sandy shale that are either from the seam flora or from an entirely different flora brought in from some distance. David White (1931) discussed the

environmental aspects of the lowermost Pennsylvanian (Caseyville) flora of the Illinois Basin. He differentiated the swamp flora from an "upland" flora of the plains (underlain by limestone) between St. Louis and Rock Island.

The Carboniferous flora of the northern hemisphere had long been considered to be very uniform in lateral extent of stratigraphic units. This uniformity was, however, the effect of the search for a general rule and the grouping together of all the floras found in at least one cyclothem. Even the distinction between only 2 floras is an oversimplification, because many microenvironments within each major environment were present. Fisk (1960), for instance, illustrated 6 plant microenvironments in the recent Mississippi Delta: mudflat, natural levee, forest swamp, fresh marsh, brackish marsh, and salt marsh.

COMPARISON OF FLORAS OF NO. 2 COAL AND FRANCIS CREEK SHALE

Several factors influence the validity of the comparisons (table 3) of the No. 2 Coal Flora, interpreted from spore data, and the Mazon Creek Flora, reconstructed from plant compressions:

1. Plants that produce the largest number of spores or fructifications and other organs tend to be disproportionally represented in spore assemblages and compressions. This distorted picture of the actual flora does not affect the comparison of floras in the same facies, but may cause apparent differences between floras of different environments.
2. Spores with certain kinds of ornamentation and structures such as bladders are widely disseminated by wind and water.
3. Prevailing wind and water current direction distributes spores and other parts of plants unequally and mixes plants from different environments.
4. Spore exines that are resistant to decay are more frequently preserved than weakly resistant exines. Plants with thick cuticles and large amounts of suberin and lignin in their tissues are more likely to be fossilized. Some lower plant groups, such as fungi, bryophytes, and certain algae, are infrequently preserved in the fossil record.
5. Different maceration techniques provide different proportions of spore taxa as illustrated by Hughes, Jekhowsky, and Smith (1964).

TABLE 3 — COMPARISON IN PERCENT OF THE FLORAS OF THE COLCHESTER (NO. 2) COAL, THE FRANCIS CREEK SHALE, AND THE LOWER KITTANNING COAL ROOF SHALE OF WEST VIRGINIA

Plant group	Spores (No. 2 Coal)		Plant megafossils (Francis Creek Shale)			Megafossils (Lower Kittanning Coal roof shale)
	East and west of La Salle Anticlinal Belt (%)	Ancona- Garfield Structure (%)	Janssen 1946 (%)	Stewart 1950 (%)	ISGS Collection (%)	Gillespie and Clendenning 1962 (%)
Lycopside	60-78	46	6	7	14	9
Sphenopsids	3-8	4	20	11	17	22
Ferns	15-27	42	26	48	24	19
Pteridosperms	2-3	2-3	44	34	44	49
Cordaites	2-5	2-5	2	0.3	0.5	—
Others	1	3	2	—	.5	1

6. Comparison of the statistical analysis of small and large spore assemblages is difficult because analysis of the 2 assemblages is usually done separately. The count of the pteridospermic Monoletes in the spore population is especially affected by this procedure.
7. Plant compressions obtained from one or a few localities over a short time interval, especially in strip mining operations, do not provide as good a representation of the entire flora as compressions collected at a large number of locations over a long time interval. Other collecting factors that affect plant representation include the areas accessible to collectors, method of building spoil piles in strip mines, erosion of spoil piles, and the number of fossils discarded or overlooked by amateur collectors.
8. During periods of rapid sedimentation, more plants are buried than in periods of slow sedimentation.
9. Errors in taxonomic interpretations are possible.

Although many of these factors may present an erroneous picture of a single fossil flora, 2 or more floras in the same facies tend to be altered in approximately the same extent and direction. However, more serious problems, such as not knowing the number of spores and leaves produced by fossil plants, are encountered when comparing spore floras with compression floras.

A comparison of percentages of major plant groups in the 3 collections of Mazon Creek plant compressions and the compressions from above the Lower Kittanning Coal shows a rather close correlation (table 3). Gillespie and Clendening (1962) found a flora from the roof shale of the Lower Kittanning Coal containing many of the same species as the Mazon Creek Flora, but the number of species was much smaller. This might be due to farther transport or to very special growing conditions. Of the 1000 specimens counted, the pteridosperms account for nearly 50 percent, the sphenopsids, which are more common than in the Mazon Creek Flora are second (22 percent), closely followed by ferns (19 percent). Lycopods are the rarest plants, and Cordaites has not been reported.

The most striking differences between the No. 2 Coal Flora and the Mazon Creek Flora is the very small proportion of lycopods and the large proportion of pteridosperms and sphenopsids in the latter. Caution is necessary in comparing the percentages because of the difficulty in assessing the proportion of pollen to pteridosperms in the coal. In the vicinity of the Ancona-Garfield structure, lycopod spores decrease in proportion and fern spores increase in importance. Cordaites is of minor importance in all the floras. Other evidence of the difference in the No. 2 Coal and Mazon Creek Floras is the presence of spores in some fructifications of the Mazon Creek Flora that have not been found in the No. 2 Coal (unpublished data).

CONCLUSIONS

The correlation of major plant groups with various environments that existed during peat accumulation of the No. 2 Coal is listed below and schematically illustrated in figure 2.

- Swamp, wet - lycopod (Lepidodendrales), fern, Cordaites (rare) - association
- Swamp, dry - fern, lycopod (Lepidodendrales and Sigillarian), sphenopsid - association
- Levees and floodplain - pteridosperm, fern, sphenopsid - association
- Upland - pteridosperm, Cordaites, Noeggerathiales (rare) - association

Significant upland forms have not been observed in spore assemblages of the No. 2 Coal or from compression fossils from the Francis Creek Shale. Pfefferkorn has observed (unpublished data) an upland

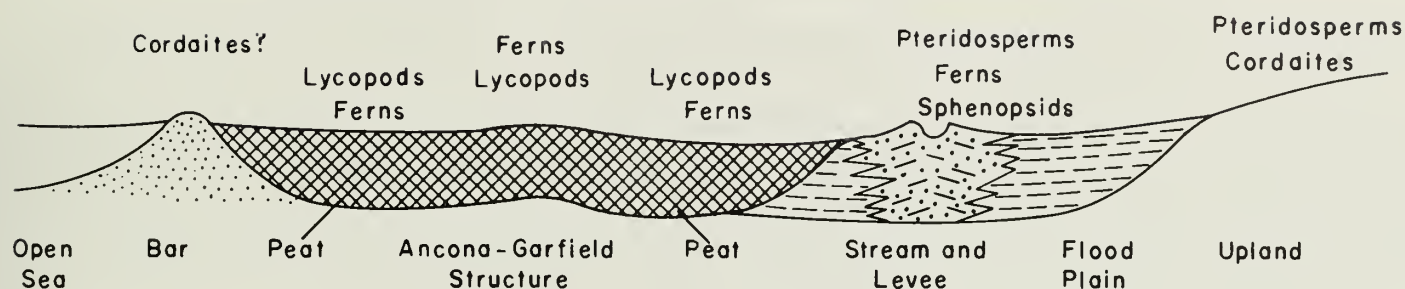


Fig. 2 - Schematic interpretation of floral distribution in sedimentary facies in the Illinois Basin during time of deposition of Colchester (No. 2) Coal.

compression flora in western Illinois and Peppers (1964) has recorded an upland spore flora from younger Pennsylvanian marine shales in Illinois.

The floral succession during peat accumulation of the No. 2 Coal in northern Illinois apparently began with primarily an arborescent lycopod assemblage that was growing in quiet, shallow water. As the water table lowered, ferns and sphenopsids became more abundant, but lycopods were still the most important group.

A second flora, a fern-lycopod association, is indicated by local variations in the spore assemblage in the No. 2 Coal in the region of the Ancona-Garfield structure and the Cardiff area. This may indicate a slightly higher elevation during the life of the No. 2 Coal swamp flora. Sigillarian lycopods, Filicales, and Sphenophyllales were better represented throughout deposition of the peat, in the Ancona-Garfield and Cardiff areas. In fact, at times the latter 2 groups may have existed in greater numbers than even the arborescent lycopods. The water table was probably lower and the water less brackish than in the remaining area of peat accumulation. The spore population represents a flora intermediate between the flora near the base of the No. 2 Coal, in which arborescent lycopods are prevalent, and the Mazon Creek Flora of the overlying Francis Creek Shale, in which pteridosperms and ferns are most common.

The Mazon Creek Flora was probably derived from a plant community that populated slightly higher elevations where the water table was lower than in a coal-forming swamp. A flora even farther upland and more distant from peat swamps was probably dominated by gymnosperms, including *Cordaite*, which was probably the source of large numbers of *Florinites*. Chaloner (1958 and 1959), Chaloner and Muir (1968), and Cross (1968) pointed out that a disproportionate number of wind-borne saccate pollen grains, such as *Florinites*, would be found far offshore in marine sediments as described by Neves (1958) and Peppers (1964). However, since cordaitalean plants make up only about 1 percent of the Mazon Creek Flora, it seems unlikely that this flora could be considered an upland flora. Rather, the Mazon Creek Flora probably inhabited a nearshore deltaic environment along the floodplains, mudflats, and levees.

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LIMESTONES AND PHOSPHATIC ROCKS FROM THE SUMMUM AND LIVERPOOL CYCLOTHEMS IN WESTERN ILLINOIS

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INTRODUCTION

In western Illinois, a fresh water nodular limestone is developed below the Summum (No. 4) Coal. Thin, brackish water limestones and/or phosphatic beds are found above the Colchester (No. 2) Coal of the Liverpool Cyclothem and the Summum (No. 4) Coal, along with an overlying sequence of marine limestones. This study emphasizes the lithology of the lowermost marine limestone unit of the Oak Grove Limestone Member (Liverpool Cyclothem) and its spatial relation to the underlying Francis Creek Shale Member at the United Electric Coal Companies, Banner Mine. The marine Hanover Limestone Member of the Summum Cyclothem was not studied.

UNDERCLAY LIMESTONE

Discontinuous but widespread argillaceous limestones are present in the lower part of the claystone which underlies most of the major coals in the Illinois Basin. The limestones average one foot or less in thickness, are generally nodular, and contain claystone inclusions. They grade upward into a 2- to 3- feet thick calcareous portion of the underclay which contains small limestone nodules (Norman, 1959). The underclay limestones do not generally contain invertebrate fossils, although *Spirorbis* and ostracods may be found. Limestones which are similar in lithology are found in much thicker units below the coals in the Appalachian coal fields.

These sediments in the Illinois Basin formed in a limnic, fresh to brackish water environment of deposition and grade laterally into marine deposits to the west of Illinois. However, a few of the underclay limestones in Illinois are marine and grade into fresher water deposits to the east, either in Illinois or Indiana.

The lowermost limestone of the Summum Cyclothem is a good example of these deposits. Richard Inden (1968) has correlated the open marine Breezy Hill Limestone (named by W. G. Pierce and W. H. Courtier, 1937, for exposures at Breezy Hill, Crawford County, Kansas) in eastern Kansas, with the underclay limestone of the Mulky Coal in Missouri, and the Summum (No. 4) Coal Member in Illinois. The Breezy Hill Limestone has been geographically extended into Missouri (Howe, 1956 and 1961) and designated a member of the Mulky Formation. Following the work of Inden, the name Breezy Hill Limestone Member (Carbondale Formation) in this report will refer to the underclay limestone below the Summum (No. 4) Coal Member in western and northern Illinois.

The Breezy Hill Limestone in western Illinois is typical of the normal fresh water underclay limestone. The limestone may be developed over either the channel or sheet phase of the Pleasant-view Sandstone Member, or may be separated from it by a thin shale. In western Illinois, the limestone is generally silty, containing up to 20 percent coarse-grained, angular to subangular quartz silt, and is characterized by dark, irregular, silty micrite patches up to 1 millimeter in diameter. These patches are contained within, and sometimes merge with, irregular, micritic filaments 0.05 millimeters thick, which are interwoven throughout the rock (plate 7, fig. 10). The micritic patches and filaments are considered to be algal in origin and the limestone to be a fresh water deposit over

most of western Illinois. The limestone is cemented by medium-crystalline sparry calcite with some sucrosic dolomite. A few calcite-filled septarian veins are present, but they are more characteristic of the overlying small nodules in the claystone.

At Stop No. 3 (fig. 9 of the Road Log, this Guidebook), the Breezy Hill Limestone Member is not well exposed and may be poorly developed. However, several large "nodules" up to 6 inches in diameter, with typical micritic patches and filaments, can be observed at the base of the section. At the Jubilee College section (Stop No. 6, fig. 12 of the Road Log, this Guidebook), neither the Breezy Hill Limestone nor the Pleasantview Sandstone is present. The underclay of the Summum (No. 4) Coal overlies the medium gray, silty Purington Shale Member with a sharp contact. In northern Illinois at the Lowell Coal Member type section (Stop No. 7, fig. 13 of the Road Log, this Guidebook), the Breezy Hill Limestone is very sandy, and while it lacks the filamentous texture, it does contain indistinct micritic patches.

PHOSPHATIC AND SPHERULITIC BEDS

Occurrences of limestone and/or phosphatic rocks are exposed overlying the Summum (No. 4) and Colchester (No. 2) Coal Members at several localities in Fulton and Peoria counties. At Stop No. 6 (fig. 12 of the Road Log, this Guidebook), near Jubilee College State Park, a thin spherulitic limestone overlies the Summum (No. 4) Coal. Because this unit has not been recognized elsewhere, it probably has a local distribution compared to the overlying granular, phosphatic unit. Where the spherulitic limestone is absent, the phosphatic bed lies directly upon the coal, a relationship fairly well exposed at the Maples Mill section (Stop No. 3, fig. 9 of the Road Log, this Guidebook). A similar unit (Damberger, this Guidebook, p. 100) overlies a thin, pyritized plant zone on top of the Colchester (No. 2) Coal Member in areas where the Francis Creek Shale Member is absent. Where the Francis Creek Shale is present, only a pyritized plant zone is developed. The spherulitic limestone and the phosphatic units are considered to be brackish water equivalents to the more marine "transgression shell breccia" found above many of the coals in the Illinois Basin.

The spherulitic limestone maintains a thickness of about 1 inch and has irregular bedding surfaces. It is medium gray, argillaceous, medium grained, and consists of subspherical spherulites. These are fairly uniform in grain size (average 1.0 millimeter) and poorly cemented with calcite. The spherulites are composed of radiating acicular crystals of calcite; all exhibit a pseudouniaxial cross under crossed nicols and have randomly branching syneresis cracks near the center (plate 6, fig. 1). The rock may consist either of intergrown spherulites (plate 6, fig. 1) or of distinct particles which resemble small nodules which have a superimposed radial texture (plate 6, fig. 2). These spherulites may represent small algal nodules or colonies which were recrystallized in this manner.

The phosphatic bed over the Summum (No. 4) Coal is dark brownish gray and contains medium grained (averaging 0.25 millimeters), poorly sorted sand-size particles, which are normally in grain-to-grain contact and cemented by coarsely crystalline calcite (plate 6, fig. 3). The grains are irregularly shaped, are composed of amorphous phosphatic material, and have a thin rind of crystalline calcium phosphate (plate 6, fig. 4). These phosphatic grains, resembling mud aggregates, were probably formed by reworking of a calcareous mud which was replaced by calcium phosphate. The rock contains several wood fragments and possible fish teeth and bone material. The cells of the wood fragments are filled mainly with phosphatic material, while the cell walls consist of finely crystalline calcite. This seems to indicate that the cells were filled or replaced by calcium phosphate before the cell walls had decayed. Phosphatization of the plant material probably took place before any extensive burial and was contemporaneous with replacement of the postulated calcareous mud aggregates.

The phosphatic band overlying the Colchester (No. 2) Coal is similar to the bed described above. It is light tan, about 1 inch thick, and consists of phosphatic grains supported by calcium phosphate and finely crystalline calcite cement. This unit is thought to have formed by syngenetic replacement of a carbonate deposit; however, unlike the phosphatic bed over the Summum (No. 4) Coal, the grains were probably supported by a mud matrix, indicating a less agitated environment of deposition. The relationship of this band to the Francis Creek Shale is well displayed at the Banner Mine (Stop No. 2 of the Road Log, this Guidebook).

MARINE LIMESTONES

The marine sequences that contain well developed limestones generally overlie a black, sheeted shale, such as the Mecca Quarry Shale Member (Smith, this Guidebook, p. 34) over the No. 2 Coal, and the Excello Shale Member over the No. 4 Coal. The Excello Shale (a black, sheeted shale above the Mulky Coal Member) was named by W. V. Searight (1953) for exposures west of Excello, Macon County, Missouri. The name Excello Shale is here extended into Illinois, being applied to similar deposits as a member of the Carbondale Formation, and recognized as a unit of the Summum Cyclothem (Smith, this Guidebook, p. 35). Although the general lithologic character of these black shales is relatively uniform, they contain several biofacies both laterally and vertically. They are characterized in part by a marginal marine fauna and usually have an abrupt contact with the overlying carbonate sequence which must have been formed in a less restricted environment.

The carbonate sequence of the Summum Cyclothem consists of a light gray calcareous shale which underlies 2 prominent limestone units in western Illinois, the Hanover Limestone Member and the Covell Conglomerate Member. The Covell Conglomerate Member, named by H. B. Willman (1939) from exposures south of Ottawa, Illinois, along Covell Creek, is a thin, widespread unit, which is found only in northern and western Illinois. It usually overlies the hummocky upper surface of the Hanover Limestone Member. The Hanover Limestone is variable in lithology, consisting of a sandy, glauconitic limestone in Knox County, and a light to bluish gray, somewhat nodular limestone in portions of Fulton County (Wanless, 1957).

The Covell Conglomerate normally varies from $\frac{1}{2}$ to 3 inches in thickness, but is over 2 feet thick in the abandoned Randall Quarry near Knoxville. It is generally medium gray, poorly sorted, and consists of fine sand to pebble size, well rounded limestone fragments which are cemented by coarsely crystalline calcite. Both the limestone fragments and the cement are often heavily pyritized. While the fragments within the conglomerate are varied in lithology (plate 6, fig. 6), most resemble water-worn particles from nodular or concretionary limestone. The particles are medium to medium dark gray and sublithographic. A few contain syneresis cracks, about 15 percent are silty to sandy, and several are partially phosphatized. Fossils within the matrix of the conglomerate are generally rare, although a few water-worn fragments of horn corals, pelecypods, and brachiopods may be present. Only shark denticals (*Petrodus*) were recognized in the conglomerate from Randall Quarry, which also contained more partially phosphatized limestone particles. In both western and northern Illinois, none of the limestone fragments contain fossils, except for a few silty particles containing calcitornellid foraminifera.

In northern Illinois, the Covell Conglomerate is much more widespread (Willman and Payne, 1942). The matrix is generally very fossiliferous, sometimes containing rounded quartz sand grains similar to those from the Ordovician St. Peter Sandstone (Willman, 1939). At a few localities in both northern and western Illinois, the upper surface of the conglomerate is encrusted by one-half inch or more of stromatolitic laminations, the product of blue-green algae. The nature of the grains and the algal encrustations indicates a marginal marine environment, and the algal laminations may be tidal features. Most of the limestone particles may have been derived from a more brackish or fresh water environment.

None of the carbonate sequence described above is present at Stop No. 3 (Maples Mill section of the Road Log, this Guidebook) where a dark gray, fissile shale rests on the poorly developed Excello Shale. At Stop No. 6 (Jubilee College section of the Road Log, this Guidebook), the Covell Conglomerate is well exposed on top of the light gray calcareous shale and has stromatolitic encrustations on its upper surface. Following the classifications developed by Logan, Rezak, and Ginsburg, 1964, the algal encrustations found along the tributary to Kickapoo Creek (Stop No. 6 of the Road Log, this Guidebook) consist of vertically stacked hemispheroids with a constant basal radius ("SH-C") and may give way upward to spaced laterally linked hemispheroids ("LLH-S"). Those encrustations found in place at the exposure along Kickapoo Creek (plate 6, fig. 5) are concentrically stacked spheroids ("SS-C") which totally encrust pebbles, indicating a higher degree of water agitation than the other forms. The Hanover Limestone is not present here, but may be represented by a zone of nodules below the conglomerate. A thin (one-half inch) limestone, containing clasts similar to the phosphatic band exposed below, abundant *Ammodiscus*, and pectinid pelecypods

near the top, is present at the base of the calcareous shale. A dark gray fissile shale similar to that at Stop No. 2 overlies the Covell Conglomerate.

In northern and western Illinois the Summum Cyclothem contains no upper shale similar to the Purington Shale or Canton Shale of the Liverpool and St. David Cyclothem respectively. The underclay of the Springfield (No. 5) Coal Member rests with a sharp contact on either dark gray fissile shale (the Covell Conglomerate) or the Hanover Limestone.

The Oak Grove Limestone Member (Liverpool Cyclothem), named by H. R. Wanless (1931) from exposures in Fulton County (SW $\frac{1}{4}$ SE $\frac{1}{4}$, Section 6, T. 5N., R. 3E.), consists of interbedded limestones and shales overlying the Mecca Quarry Shale Member. Fourteen units have been described by Wanless, most being characterized by a distinctive fauna or gross lithology, and have been traced over a wide area in western Illinois. Parts of the sequence have also been recognized in northern Illinois, southern Iowa, western Missouri, and western Indiana (Wanless, 1957).

Of the 14 units, 5 are fairly widespread limestones which have been given informal names by Wanless (1931 and 1957) and are present at the Wolf Covered Bridge section (Stop No. 5, fig. 11 of the Road Log, this Guidebook). The reader is referred to that section for the following brief descriptions of the 5 limestones.

The lowermost, or "crinoidal," limestone is thin (less than 4 inches), very impure, contains abundant crinoidal debris and calcitornellid foraminifera, while lacking the well developed pelecypod and/or brachiopod fauna that are present in the other limestone units. The "gray septarian" limestone is probably the most widespread unit of the Oak Grove Limestone Member in western Illinois. It is medium gray, argillaceous, and ranges from a few inches to 1.5 feet in thickness. It is characterized by abundant Desmoinesia muricata (Marginifera muricata) and may often be represented by concretions with septarian structure. Where this limestone is well developed, the upper and lower few inches are very impure; the upper several inches may possess cone-in-cone structure. The "Cardiomorpha" (plate 2, this Guidebook) or "pelecypod" limestone consists of a discontinuous bed of dark gray concretions ranging up to 6 inches thick. The bed contains mostly uncrushed pelecypods with several Lingula and Orbiculoidia. The "Linoproductus" (plate 1, this Guidebook) limestone is also widespread throughout most of western Illinois. It is blue gray (weathers brown), up to 1.5 feet thick, sublithographic, burrowed near the base, and characterized by abundant productid brachiopods. The uppermost limestone unit of the Oak Grove Limestone Member is the "fossil-cast" limestone, which is medium to dark gray (weathers tan), very argillaceous, and up to 4 inches thick. Gastropods are common in this unit along with a few productid brachiopods and pectinoid pelecypods, most of which are leached and exist as undeformed casts in outcrop exposures.

Wright (1965) has correlated the "crinoidal" limestone with the Ardmore Limestone of Missouri and Kansas and the "gray septarian" limestone with a similar limestone forming the cap rock of the Wheeler Coal in Missouri. She also discussed the occurrence of several other units of the Oak Grove Limestone throughout much of the mid-continent area. In northern Illinois, the Oak Grove Limestone Member is represented by dark gray, lithographic to sublithographic, sparsely fossiliferous, lenticular limestones in a medium to medium dark gray shale. These lenticular limestones are exposed above the Mecca Quarry Shale Member at both the Lowell Coal Member type section (Stop No. 7, fig. 13 of the Road Log, this Guidebook) and the Ristocrat clay pit (Stop No. 8, fig. 14 of the Road Log, this Guidebook). They are all similar in lithology and faunal content and cannot be correlated with any assurance to units of the Oak Grove Limestone in western Illinois. It is possible that the 2 thin, nodular, or concretionary limestone zones above the Lowell Coal Member (fig. 13 of the Road Log, this Guidebook) may represent the upper portion of the Oak Grove Limestone in northern Illinois. The Lowell Coal would then be correlated to a horizon near the position of the "Cardiomorpha" limestone in western Illinois (Wright, 1965).

On the field trip stops in western Illinois, the Oak Grove Limestone Member will be observed at the Banner Mine (Stop No. 2, fig. 5 of the Road Log, this Guidebook) in addition to the Wolf Covered Bridge section (Stop 5, of the Road Log, this Guidebook). However, of the 5 limestone units, only 3 have been observed at the strip mine: the "crinoidal" limestone, the "Linoproductus" limestone and the "fossil-cast" limestone. The latter two are generally exposed only along inaccessible places near the top of the highwall and are not significantly different from the Wolf Bridge exposures. The "crinoidal" limestone is, however, well exposed at this mine, often occurring as lenses varying

in thickness up to 5 feet along the highwall. The thick limestone deposits lie on top of the Mecca Quarry Shale along the upper flanks and crests of the large swales (rolls) of the No. 2 Coal and generally just off the feather edge of the Francis Creek Shale (fig. 5 of the Road Log, this Guidebook). The limestone thins and becomes shaly outward from the build-ups and may disappear completely over the thicker gray shale. The swales in the coal, the Francis Creek Shale, and the thick limestone deposits all were observed to trend in an E-W direction (approximately 45° to the highwall) through several mining operations covering highwall advancement of about 400 feet. However, the limestone is sporadically developed along this trend, varying from 1 to 5 feet in thickness.

The thick limestone build-ups that can be seen in the pit vary in lithology, but a few features are almost always present (fig. 8 of the Road Log, this Guidebook). The basal portion of the limestone is extensively burrowed (fig. 7 of the Road Log, this Guidebook), with many of the burrows continuing on into the Mecca Quarry Shale, which is generally thinner than normal under the thick limestone. The lower half of the limestone is an argillaceous, crinoidal spararenite containing grain-supported particles averaging 0.5 millimeters in diameter. Rounded inclusions of dark gray to black shale up to 1 inch in diameter are common within this interval, decreasing in abundance upward. Near the middle of the limestone is a $\frac{1}{2}$ to 6-inch light brown micrite band. In the deposits where this band is thick, it usually contains abundant mud-supported fragments of both well preserved crinoidal debris and the phylloid algae Archaeolithophyllum (plate 7, figs. 7 and 8). Where this band is thin, it may overlie a thin productid brachiopod horizon, in which case it contains abundant brachiopod spines. The upper portion of the limestone is similar to the lower sparite zone, but finer-grained (average 0.3 millimeters in diameter), and may be thin or absent where the underlying micrite band is thickest. This part of the limestone is almost always characterized by abundant, fairly well sorted phylloid algal fragments in which Archaeolithophyllum predominates. The above genus may be well preserved due to selective pyritization of the cell interiors, in which case both the perithallus and hypothallus cells may be observed (plate 7, fig. 9); however, no conceptacles were observed in any specimens. Usually, the fragments are heavily recrystallized and only portions of the hypothallus tissue are recognizable. This algae was not observed to occur as laminated encrustations which are characteristic of this genus in several other Pennsylvanian limestones in the Illinois Basin. However, encrusting forms of this algae are present in Fulton County (SW $\frac{1}{4}$ SW $\frac{1}{4}$, Section 1, T. 5N., R. 4E.) within a poorly exposed limestone which is tentatively correlated with the "crinoidal" limestone.

The upper sparite zone grades up into a zone several inches thick, in which the limestone occurs as fragments and lenses (up to 2 inches thick) in a medium dark gray, calcareous and fossiliferous shale matrix. Small calcitornellid foraminifera are abundant in this zone although they also occur throughout the rock.

The limestone build-ups may have formed above wave base along ridges parallel to the shorelines and may have been roughly constructed in an en echelon pattern. The deposits built up to a position where the growth of phylloid algae could begin. The initial growth of algae was, in most cases, contemporaneous with the formation of the micrite band. The limestone deposits were possibly built up to where they were partially exposed; then the upper portion of the sediment was desiccated and reworked into the overlying shale.

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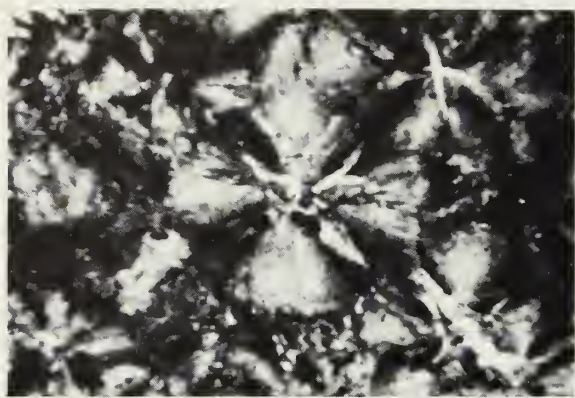
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PLATES 6 AND 7

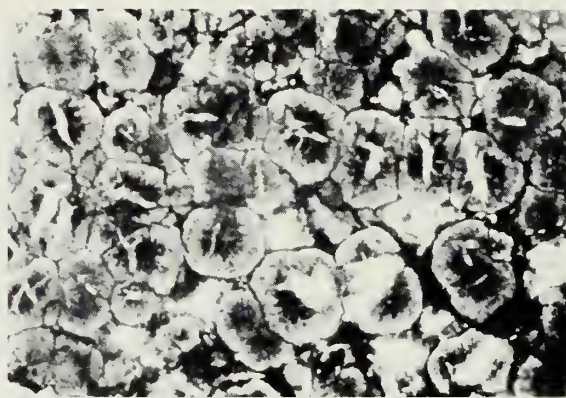
Figure

1. Spherulitic limestone (thin section-crossed nicols) from Stop No. 6 showing intergrown spherules of radiating acicular calcite.
2. Spherulitic limestone (thin section-plain light) from Stop No. 6 showing distinct nodular spherules in partially recrystallized zone.
3. Phosphatic unit (thin section-plain light) from Stop No. 3 showing texture and character of phosphatic grains.
4. Phosphatic unit (thin section-crossed nicols) from Stop No. 6 showing character of cement and amorphous grains. Note areas where calcite cement is partially recrystallized to acicular texture, a common feature where this bed overlies the spherulitic limestone.
5. Covel Conglomerate Member (polished sample) from Stop No. 6 showing conglomerate texture and concentric ("SS-C") algal laminations around a large grain on the upper surface.
6. Covel Conglomerate Member (thin section-plain light) from Stop No. 6 showing rounding and variable texture of the grains. Note sandy pelletoidal grain and dark, finely crystalline grains.
- 7-9. Oak Grove Limestone Member, "crinoidal" limestone unit, from Stop No. 2.
 7. Polished sample showing: A. argillaceous biosparite zone, B. thin micrite band, and C. phylloid algal sparite zone.
 8. Thick micrite band (thin section-plain light) showing several poorly preserved Archaeolithophyllum fragments. Note encrusting calcitornellid foraminifera near lower left.
 9. Phylloid algal sparite zone (thin section-plain light) showing pyritized fragment of Archaeolithophyllum with small, well defined outer perithallic cells and inner polygonal hypothallic cells.
10. Breezy Hill Limestone Member (polished sample) from Stop No. 3 showing micritic filaments.



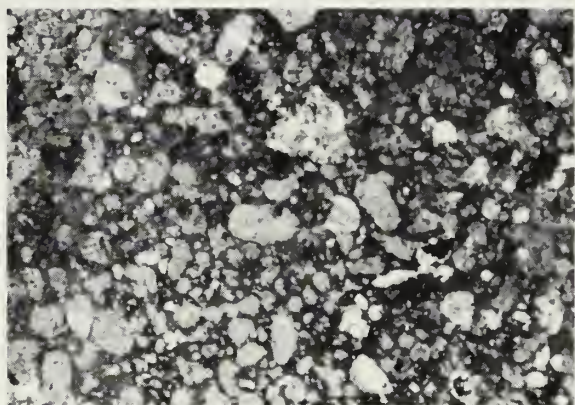
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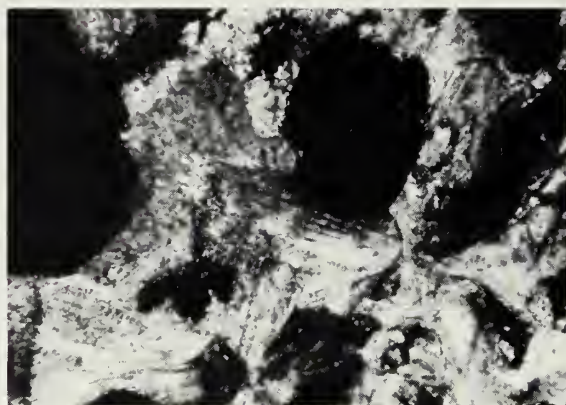
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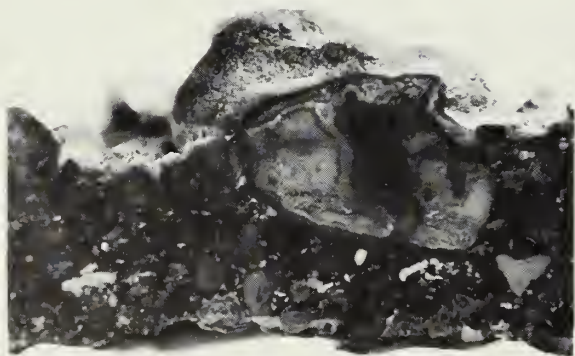
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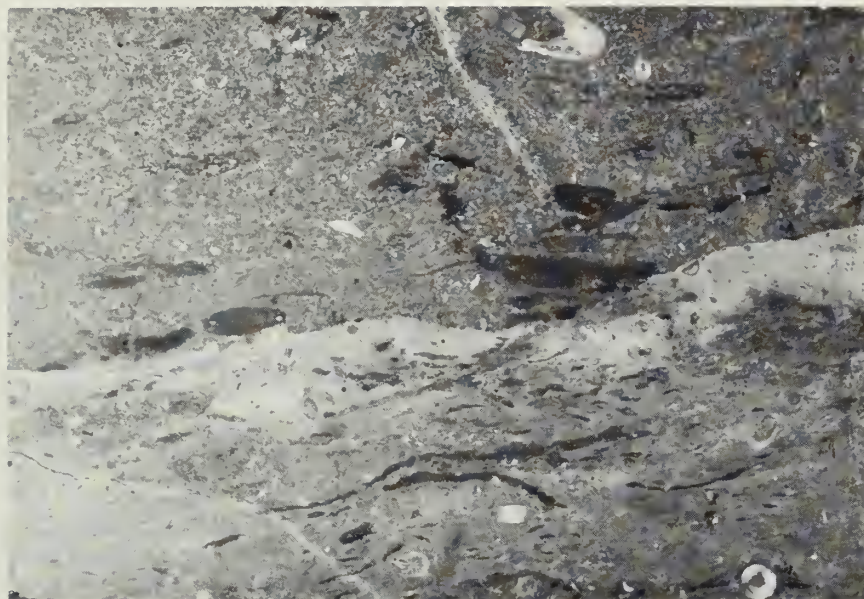
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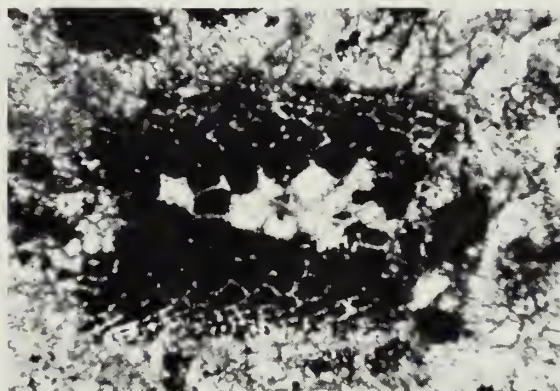
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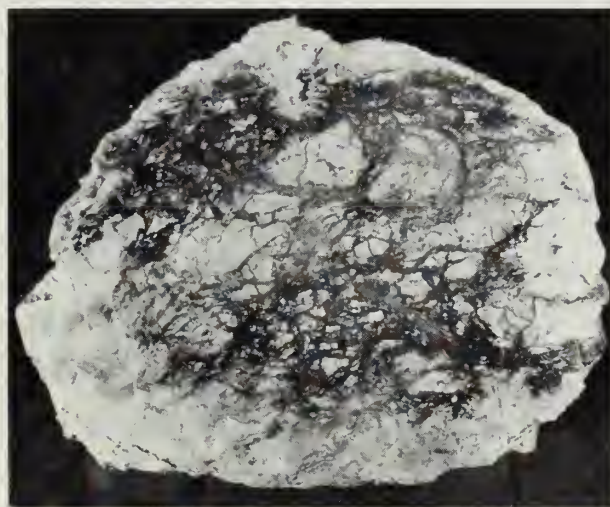
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CLAY MINERALS ASSOCIATED WITH THE COLCHESTER (NO. 2)
COAL OF THE ILLINOIS BASIN

Randall E. Hughes
(Illinois State Geological Survey)

INTRODUCTION

Studies of outcrop and borehold records by Wanless (1939) indicate that the underclay, coal, and black shale of the Liverpool Cyclothem of Illinois are among the most widespread stratigraphic units of the Pennsylvanian of the central and eastern United States. The availability of many outcrops, mines, and drill holes has generated extensive studies of these units. Complete stratigraphic records of a number of sedimentary environments have also greatly encouraged studies. The existence of black shale, gray shale and limestone facies in strata overlying the coal (Wanless, 1939) and of a variable clay mineral suite in the underclay (Parham, 1962) have increased current interest. The variation in clay mineralogy of the underclay of the Colchester (No. 2) Coal Member of the Carbondale Formation forms an essential part of the "type" system used by Parham (1962) to describe the general range of variation of underclays. Underclays were typed by Parham as a series of letters (A to Q) representing variations in clay mineralogy by X-ray determination. The mineralogic information obtained about the units in general, and the claystones and shales in particular, has been useful in potential and actual economic development by pottery and ceramic, coal, and lightweight aggregate industries in the state.

Data derived from a study of these units may be applied to models or predictions of clay diagenesis, Pennsylvanian paleogeography, paralic depositional mechanics, lithogenesis, and characteristics of Pennsylvanian source materials.

CLAY MINERAL ZONES

The underclay of the Colchester (No. 2) Coal, like most underclay units, is the most mineralogically variable unit of the cyclothem. The underclay of the No. 2 Coal is of particular importance to Parham's characterization of underclays because several of the most shoreward and kaolinite rich localities (types A to G) are best developed in this underclay. Figure 1 is a map showing the variations in the underclay as given by Odom and Parham (1968). A modification of the representative (ideal) X-ray diffractograms of the three discrete compositional clay suites of Odom and Parham's "type" underclays is given in figure 2.

A generalization of the changes in both clay and nonclay mineralogy, based on whole sample determination of the quantitative mineralogy of some Illinois underclays, is given in figure 3. The selective occurrence of feldspar and pyrite, as well as the existence of two types of kaolinite (poorly crystallized and well crystallized) in the underclays, is of special importance. Feldspar does not occur in sufficient quantities to be detected by X-ray diffraction techniques in underclays A to G but is present in underclays H to M. As the amount of well crystallized kaolinite increases in underclays N to Q (fig. 3), feldspar decreases or cannot be detected. Since quartz abundance, determined by X-ray quantification, does not vary in any regular way, it is assumed that sorting and differential flocculation does not explain either the distribution of feldspar, of either kaolinite type, or of associated clay minerals.

A model of underclay genesis that explains both the nonclay and clay patterns has been generated. Particle morphology and sample texture, as interpreted from scanning electron micrographs (SEM), supports the genetic association of soil, shale and gley-type clay particles by similarity and the authigenic euhedral form of kaolinite in underclays N to Q. The interpretation of the genesis of the underclay is amplified and supported by investigation of clay minerals in coals. A to G underclays contain poorly crystallized kaolinite similar to that developed in soils; therefore, it is assumed that the original source material, illite, chlorite, and feldspar, was altered at the site of deposition by an oxidizing soil environment to form kaolinite and degraded illite or expandable minerals. In areas farther away from regional highs, the depositional environment was unaffected by excessive downward (oxidizing) or upward (reducing) water movement. These areas (H to M) might be referred to as dominantly depositional and are represented by relatively well preserved source material (illite, chlorite, and feldspar). Finally, in swampy (gley) areas where the sediments were covered with water, the activity of plant-generated acids and plant uptake of K^+ and Mg^{++} progressively altered illite, chlorite, and feldspar to produce an expandable clay with increasing amounts of associated authigenic kaolinite (underclays N to Q).

Kaolinite believed to have formed in swampy areas is well crystallized and authigenic, as indicated by X-ray crystallinity and euhedral form (SEM). The reducing environment of gley type underclays (N to Q) tends to produce more homogeneous, well crystallized expandable minerals than those associated with soil underclays. Similar improvement in smectite (a clay mineral that expands up to about 17\AA when placed in a glycol atmosphere for several days) crystallinity has been associated with the gley environment by Willman et al. (1966) and Hughes and White (1969). Occasionally clay minerals are observed to vary randomly in an underclay profile. This sort of change is the result of the type of environment that affected each increment (flood) of sediment. The existence of fresh water limestone, rare flint clays (Hughes and White, 1969), root and plant material, and occasional laminated underclays can be the result of a deltaic distributary pattern and the environment in which the sediments are deposited.

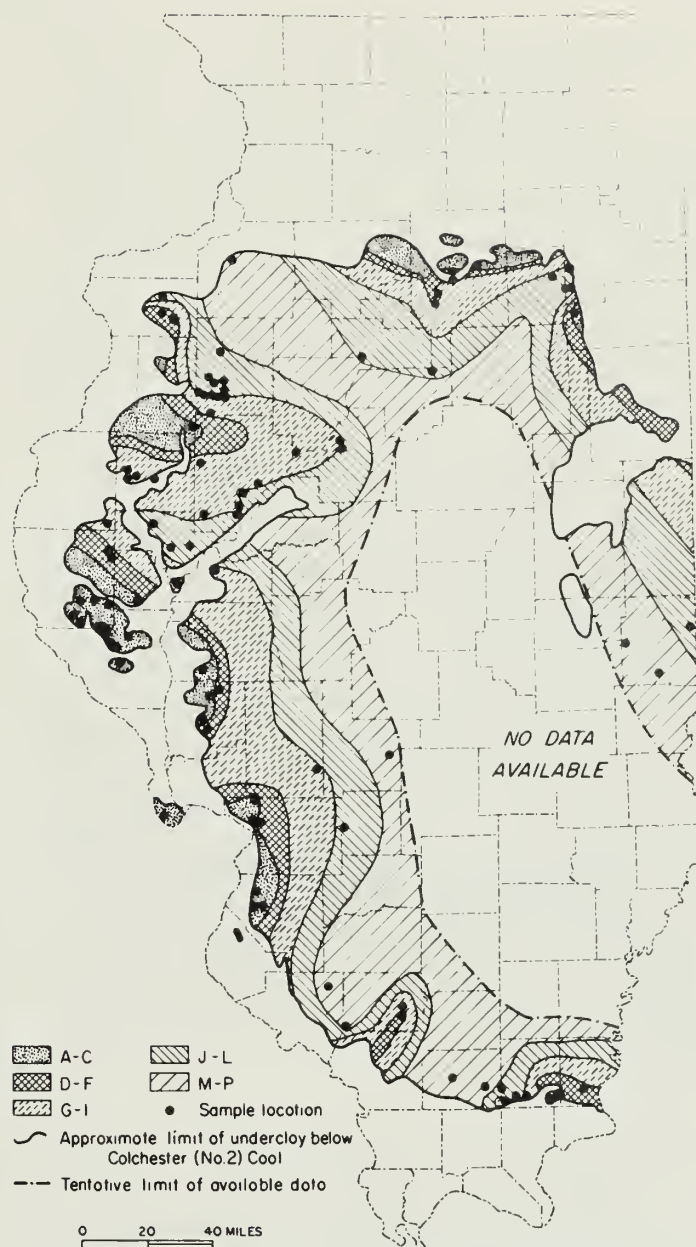


Fig. 1 - Clay mineral zones of the underclay below the Colchester (No. 2) Coal Member, after Odom and Parham (1968).

FEATURES ASSOCIATED WITH NO. 2 COAL

The minerals present in Illinois coals represent only an extension of depositional-gley underclay mineralogy. The clay mineralogy of composite mine samples of Illinois coals range from types M to Q in Parham's classification. There is considerable pyrite, an absence of feldspar, and a quantitatively

variable, but consistent, presence of authigenic kaolinite (Gluskoter, 1967).

A greater mineralogic variation than is found in underclays is indicated by the different petrographic units making up a banded coal. In pure vitrain or fusain bands, authigenic kaolinite dominates both as cleat partings and dispersed mineral matter. Clarain bands contain more expandable and illitic clay minerals. The clay mineral composition of the individual coal bands varies from the equivalent of a K underclay in clarain bands to beyond Q or to a pure kaolinite composition in vitrain or fusain bands.

Clay minerals in shale bands, or partings, in coal have been examined to a limited extent. In general the clay mineralogy of clay bands in Illinois coals is similar to many underclay types. Few illite-chlorite compositions have been observed and feldspar is generally absent. Kaolinite, either soil (poorly crystallized), or gley type (well crystallized), is always present. Pyrite content varies widely and seems to be more abundant with well crystallized kaolinite, similar to the pattern observed in underclays (fig. 3). Clay bands are interpreted to be the result of normal sediment flooding into a consistently acid environment. Oxidizing (soil) or reducing (gley) mineral suites were formed in response to variations in Eh. Illite-chlorite compositions are not preserved, because the bands are thin enough to be affected by associated plant activity.

CLAY MINERALOGY ABOVE THE NO. 2 COAL

Following submergence of the peat swamp, illite-chlorite source material dominated during deposition of the roof shale. Due to the continued effect of Eh variable environments, gray shale is normally deposited in the areas of former distributaries. Black shales and limestones are present over the coals in areas where higher sulfur, coal and underclay suites (comparable to Q-type suites) are more common (Gluskoter, 1967; Hopkins, 1968, and Gluskoter and Simon, 1968). Relatively high kaolinite content near the coal in many roof shales (Webb, 1963) represent the continued activity of plant-generated humic acids early in the time of deposition of the roof shale.

The lesser degree of alteration of illite, chlorite and feldspar in shales above the coal, is due to extensive submergence, more rapid sedimentation, and a progressive increase in salinity. In a few zones and in concretions formed around plant fossils, authigenic kaolinite and expandable clay minerals are well developed, as shown by an example from a concretion in the Francis Creek Shale of the Mazon Creek areas as reported by Bohor and Hughes (1970). The well crystallized kaolinite

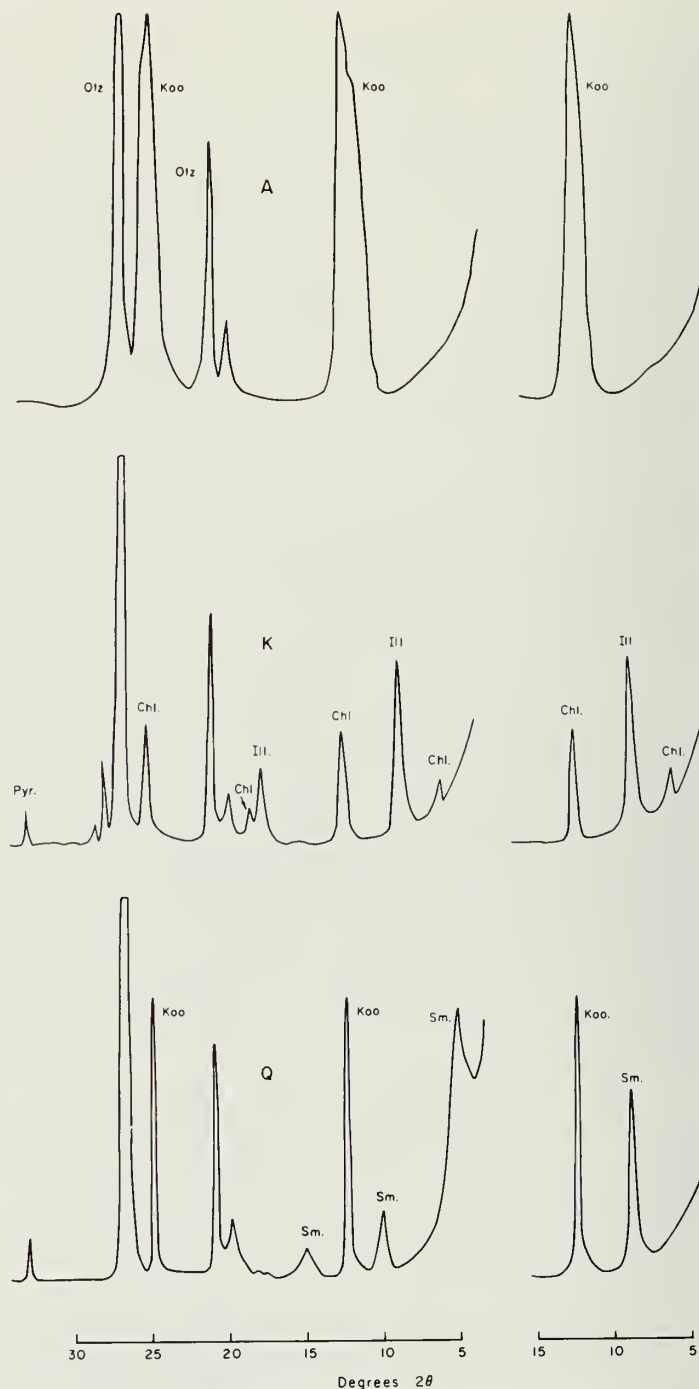


Fig. 2 - Generalized glycol (left) and heated 330°C (right) X-ray diffractograms of extremes of underclay mineralogy. Qtz.-quartz, Kao.-kaolinite, Chl.-chlorite, Ill.-illite, Pyr.-pyrite, Sm.-smectite.

in this sample replaces a leaf fragment that forms the central plane of the ellipsoidal concretion and fills dessication cracks. With few exceptions, the gray shale overlying the coal commonly appears as channel filling with local lateral spreading of sediment and very small amounts of associated organic matter. The gray shale is, therefore, assumed to have been deposited and compacted in relatively oxygen-rich water of relatively low salinity.

In areas farther away from distributary channels, reduced sedimentation rates and increased rates of generation of organic material contributed to increases in the development of authigenic apatite, pyrite, and carbonate minerals and kaolinite. The minerals observed actually tend to increase individually or in groups, and may help to distinguish between varying environments within the black shale areas. Kaolinite and pyrite-rich sediments may indicate low salinity areas with acid and sulfate waters, while apatite may indicate an increase in salinity and a change in the associated organic (fauna and flora) material. The black shale environment, as contrasted with the gray, represents lower Eh and more saline environment. As compared to the mineralogy in coals and underclays, both gray and black shales above the coal were deposited in more saline water with less alteration of minerals, due to the growth and decay of organic material.

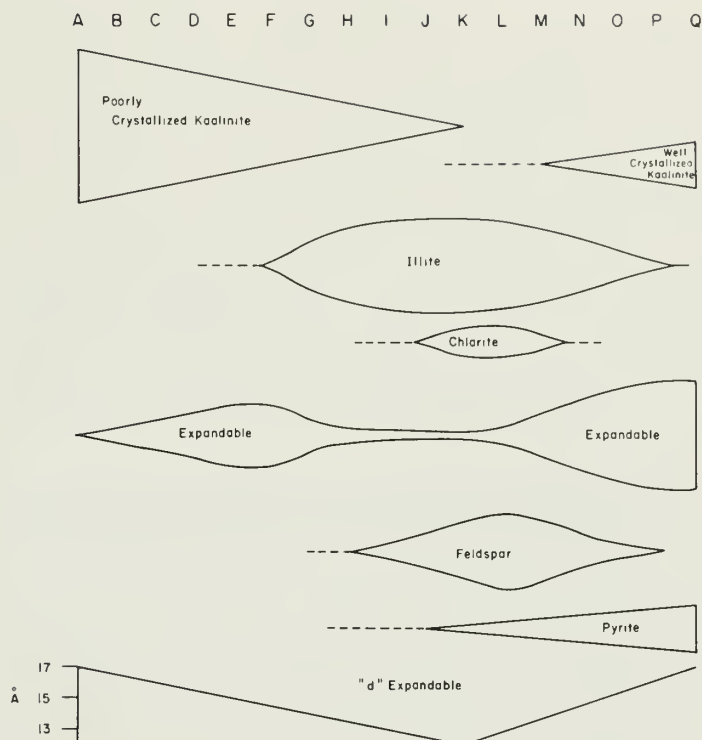


Fig. 3 - Generalized lateral variation in underclays from distributary channels (A) to saturated gley areas (Q).

SUMMARY

Variations in the clay materials associated with the Colchester (No. 2) Coal of the Illinois Basin result from the effects of environments of deposition on an illite, chlorite, feldspar and quartz source material. Water chemistry, Eh, type and chemical characteristics of organic material, and the degree of natural and bacterial decomposition distinguish the environments observed. Rate of deposition, range of water depth, and minor interface effects between associated units determine the degree to which environments have transformed the source material. Underclays demonstrate the greatest range of clay mineral types. Composite samples of clays in coals are less variable, and shales above the coal appear to represent the least altered source material.

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DISTRIBUTION OF SULFUR IN ILLINOIS COALS

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INTRODUCTION

It has long been recognized that the sulfur in coal contributes to boiler fouling and associated problems of boiler tube corrosion, and coal used for metallurgical coke has long had sulfur limits placed upon it. However, the previous level of interest in sulfur in coal is relatively small when compared to the growing public concern with air quality problems. Research concerning sulfur in coal has thus intensified in recent years, and investigations have included such problems as the mode of occurrence of sulfur varieties in the coal, the removal of a portion of the pyrite by preparation techniques prior to combustion, and the removal of SO_2 from the power plant gaseous effluent.

Sulfur occurs in coal in organic combination (organic sulfur), as sulfate minerals (sulfate sulfur), and as sulfide minerals (pyritic sulfur or sulfide sulfur). Free sulfur (native sulfur) in coal has also been reported in a few instances, but its occurrence is rare enough to be disregarded for most purposes. It has not been reported in Illinois coals.

Sulfate sulfur is present as either calcium sulfate dihydrate (gypsum) or as one of the iron sulfates which form upon the oxidation of pyrite. While iron sulfate is negligible in fresh coal samples, the amount of sulfate sulfur in a coal sample increases rapidly as the sample is exposed to weathering.

The term "pyritic sulfur" refers to either of two dimorphs of ferrous disulfide (FeS_2) - pyrite or marcasite. The two minerals have identical chemical compositions but different crystalline forms. Pyrite is isometric (cubic) and marcasite is orthorhombic. They can be distinguished only by their crystalline structure, which is usually determined by X-ray analyses. Pyrite is the most commonly reported dimorph, although marcasite is often mentioned as occurring in lesser amounts. While pyrite is the dominant sulfide, marcasite has not yet been substantiated as occurring in Illinois coals.

SULFUR CONTENT OF ILLINOIS COALS

Gluskoter and Simon (1968) reported on the results of sulfur analyses of Illinois coals and some of their observations are summarized below. Their data was derived from 474 chemical analyses of many different coals on which varieties of sulfur were determined (sulfate sulfur, pyritic sulfur, and organic sulfur). All coals analyzed were either face-channel samples or drill-core samples, and mineral bands in the coal over 3/8-inch thick were omitted from the sample prior to analysis.

Sulfate Sulfur

Sulfate sulfur is present in minor amounts in nearly all of the samples analyzed, ranging from a low of 0.00 percent to a high of 0.88 percent. Values over 0.20 percent are relatively rare. The mean of 361 sulfate sulfur analyses on face-channel and drill-core samples of Illinois coals is 0.08 percent, and the mode is between 0.02 and 0.04 percent.

Organic Sulfur

Organic sulfur values range from a low of 0.27 percent to a high of 2.98 percent in Illinois coals that have been sampled to date. The mean value for organic sulfur of all coals is 1.46 percent.

Pyritic Sulfur

The range in values of pyritic sulfur in face-channel and drill-core samples is greater than that of organic sulfur. Pyritic sulfur extends from a low of 0.00 percent to normally high values of 4.0 to 5.0 percent, with a few extremes as high as 7.5 to 9.0 percent. The mean value of pyritic sulfur in coals sampled is 2.06 percent.

Total Sulfur

Total sulfur in face-channel samples of Illinois coals ranges from a low of less than 0.50 percent to normally high values of 5.0 to 6.0 percent, with a few extreme cases approaching 10 percent (one sample exceeds 10 percent). The extremely high-sulfur coal samples contain primarily pyritic sulfur. The mean total sulfur content for all 474 face-channel samples is 3.57 percent.

Relationship Between Pyritic and Organic Sulfur

The ratio of pyritic sulfur to organic sulfur in face-channel samples of Illinois coals ranges from 0 (three face-channel samples of one coal for which chemical analysis showed no pyritic sulfur) to 13.67. The correlation coefficient for this relationship is 0.31, and the mean value for the ratio of pyritic sulfur to organic sulfur is 1.56. There is approximately $1\frac{1}{2}$ times as much pyritic sulfur in a sample as there is organic sulfur.

The organic sulfur content of the coal does not vary greatly over relatively small areas. For example, a relatively constant organic sulfur content is shown for the 13 samples of the Colchester (No. 2) Coal Member collected from the Banner Mine (Hopkins and Nance, this Guidebook, p.97). Here the total sulfur (dry basis) varied from 2.76 to 7.34 percent, while the organic sulfur remained essentially constant at about 2 percent.

SULFUR IN THE BANDED INGREDIENTS OF COAL

A study was made by Survey personnel (Cady, 1935) of the distribution of the forms of sulfur in the megascopically distinguishable banded ingredients of coal. The banded ingredients sampled were vitrain, clarain, and fusain. Durain, or dull splint coal, is very rare in Illinois coals; therefore, none was sampled.

In general, the pyritic sulfur content is greater in the fusain than in other bands, although the amount varies widely in different fusain samples. This is due to the amount of pyrite found in the fusain cavities. The organic sulfur content of fusain was, in all cases, less than 1 percent.

Vitrain and clarain have a higher organic to pyritic sulfur ratio, all generally greater than 1. The organic sulfur content of vitrain is usually lower than clarain from the same coal. The preceding generalizations notwithstanding, Cady (1935) concluded that the variations in organic sulfur content of Illinois coals cannot be ascribed only to variation in relative amounts of banded ingredients.

VERTICAL DISTRIBUTION OF SULFUR WITHIN THE COAL SEAM

Although there is not complete agreement concerning the vertical distribution of sulfur within the coal seam, one nearly unanimous observation is that the distribution of organic sulfur is much more uniform than that of pyritic sulfur.

Many workers have noted a tendency for total sulfur (and therefore pyrite) to be concentrated near the upper and lower margins of the seam. This was generally, but not universally, the case for a series of benched drill-core samples of the Harrisburg (No. 5) Coal and the Herrin (No. 6) Coal in southern Illinois described by Gluskoter and Simon (1968).

Some investigators have concluded that the pyrite and total sulfur content of the coal was determined early within the peat stage. However, authigenic pyrite, which formed later, does occur in coal. The large pyrite-filled cleats, or nearly vertical joints, are of later origin. If these fractures had been filled during the peat stage, they would necessarily show the effects of further compaction of the coal. If secondary pyrite can be shown to enter the coal in this manner, then perhaps other occurrences of pyrite could be explained similarly. In any case, the coal-underclay, coal-shale, or earlier peat-clay boundary is an interface across which geochemical conditions would be expected to change and provide a location for precipitation of iron sulfide. If at least some portion of the components necessary for iron disulfide formation were supplied from outside the coal, then they would have to encounter the vertical limits of the bed before any other portion, except perhaps for fractures within the bed. The concentration of sulfur (pyrite) at the top and/or bottom of the seam and along fractures is then to be expected.

LOW-SULFUR COAL IN ILLINOIS

Four areas of relatively low-sulfur coal, all in southern Illinois, are shown in figure 1. Three of these are in Herrin (No. 6) Coal, and one is in the Harrisburg (No. 5) Coal. The average total sulfur content of the coal in the three areas of No. 6 Coal is approximately 1.5 percent, and the average total sulfur content in the No. 5 Coal area is estimated to be 2.0 to 2.25 percent. In all of these areas the coal is directly overlain by a thick (more than 20 feet) gray shale which lacks distinct marine affinities. Where the marine black "slaty" shale and/or limestone lie close to the top of the coal, the sulfur content is substantially higher.

The low-sulfur coal boundary (at about 2 percent sulfur) can be drawn with a surprising degree of accuracy by plotting the 20-foot isopach of the overlying gray shale. Figure 2 shows plots of the total sulfur (dry basis) versus thickness of the overlying gray shale from 26 core samples of the No. 6 Coal, drilled in a two-township area in the "Quality Circle" area of southern Illinois. Two percent sulfur corresponds well with the 20-foot shale thickness line, but where gray shale is less than 20 feet thick, the curve is poorly defined. The association of high-sulfur coal and overlying marine beds has also been reported for coals in U.S.S.R., Great Britain, Manchuria, Germany, and Australia.

In addition to the mapped areas of low-sulfur Nos. 5 and 6 Coals in southern Illinois, similar geologic conditions exist for every known occurrence of any considerable area of low-sulfur coal in Illinois and western Indiana. Examples include the Murphysboro Coal Member of the Spoon Formation in southern Illinois, the Danville Coal (VII) south of Terre Haute, Indiana, and certain areas of Colchester (No. 2) Coal in northern Illinois. This same occurrence has also been observed in the Croweburg Coal (a correlative of the Illinois No. 2) in the McNabb strip pits just east of Tulsa, Oklahoma, where the coal is overlain by about 25 feet of gray shale, then black shale and Verdigris Limestone.

The stratigraphic position of this gray shale is always below the black shale and limestone. In figure 3 these relations are shown in a diagrammatic section perpendicular to the elongate trend of the gray shale (and sandstone) body. The horizontal scale is quite variable but is usually less than 12 miles wide. One exception is the Francis Creek Shale Member, which occurs above the Colchester (No. 2) Coal in northern and western Illinois. Here the width of the thick shale body is as much as 50 miles.

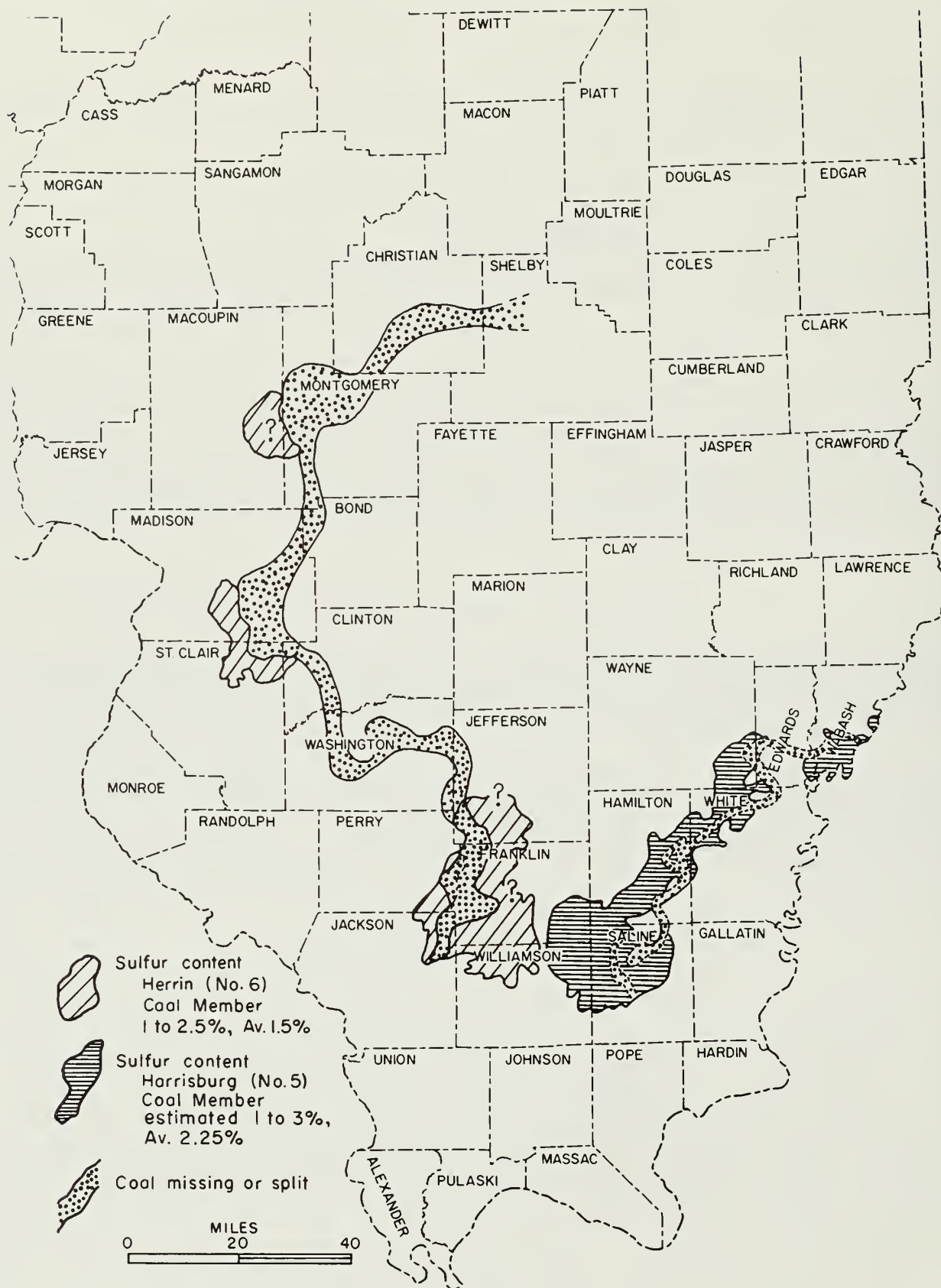


Fig. 1 - "Low sulfur" reserve areas in southern Illinois.

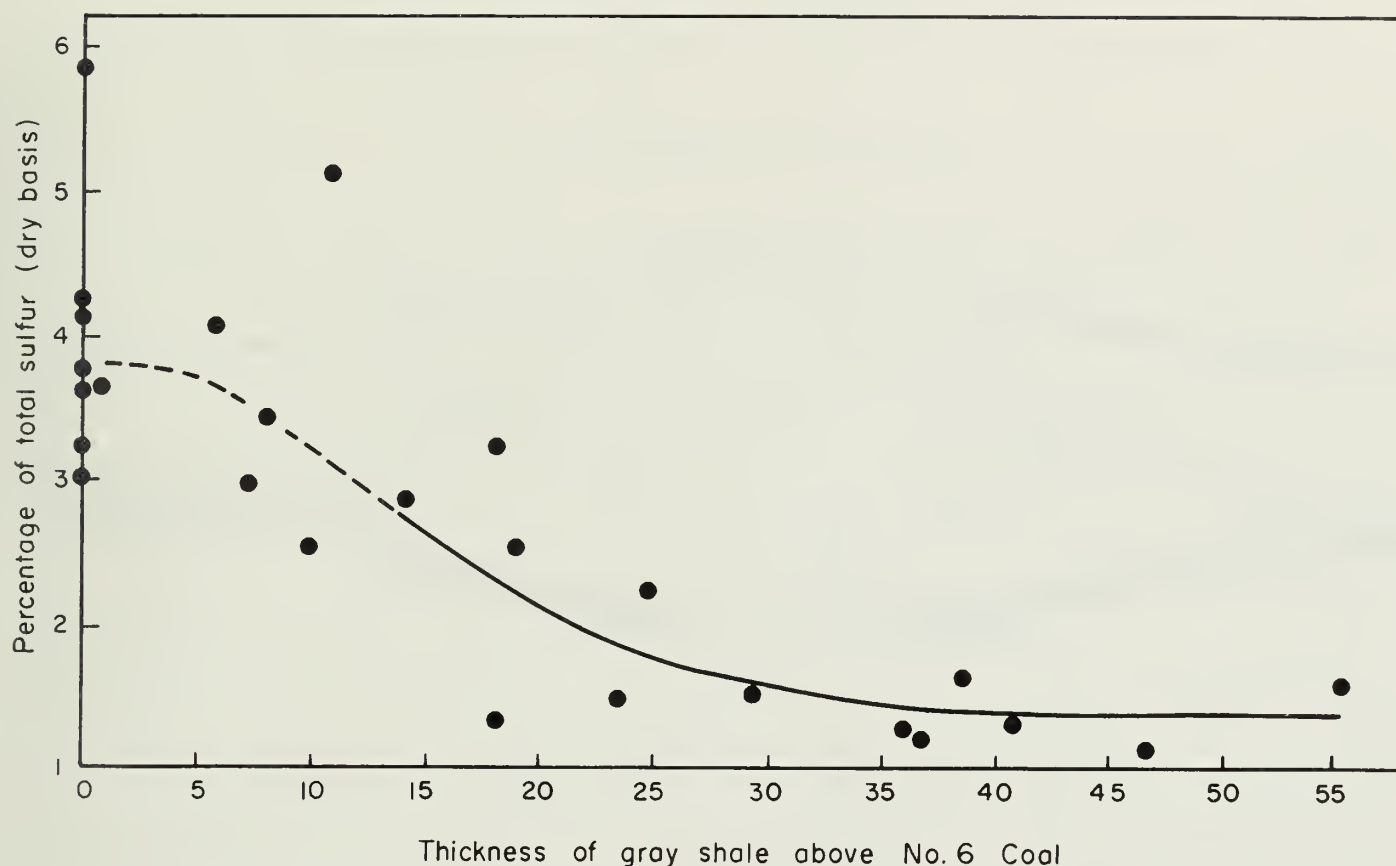


Fig. 2 - Relation of total sulfur content from 26 core samples of the Herrin (No. 6) Coal Member with thickness of the overlying gray shale, southern Illinois.

The vertical scale is also variable. Up to 75 feet of this gray shale has been observed above the No. 6 Coal in the "Quality Circle" area of Jefferson and Franklin counties, and as much as 100 feet of the Dykersburg Shale Member may be found above the No. 5 Coal (Hopkins, 1968). Thickness variations for the Francis Creek Shale are shown by Smith (this Guidebook, p. 35).

Generally the black shale and limestone do not extend completely over the gray shale; they thin out and disappear usually less than 40 feet above the top of the coal. No interfingering or interbedding of the black and gray shales has been observed; the contact, wherever seen, is sharp.

There are areas in Illinois where the coal is overlain by a thick gray shale and the coal is relatively high in sulfur. In such instances the gray shale is thought to represent a unit that occurs above the normal position of the marine limestone in the cyclic sequence of sediments characterizing coal-bearing rocks. No black shale and limestone occur related to the Danville (No. 7) Coal Member near Danville, Illinois, or in the equivalent Danville Coal (VII) in adjacent parts of western Indiana. In both high- and low-sulfur occurrences, this coal is overlain by gray shale; however, the general lithologic appearance of the shale in the two areas is different. The shale over the low-sulfur coal is quite silty, contains sandstone units, and bears plant fossils. In the higher sulfur area, the shale overlying the coal has a marine fauna characterized by several varieties of brachiopods and pelecypods, and frequently has a thin fossil layer (mostly pyritized shells) at the base.

Sulfur Content of Colchester (No. 2) Coal Member

The Colchester (No. 2) Coal has been mined extensively in northern and western Illinois. Total sulfur content of face-channel samples of No. 2 Coal ranges from 0.70 percent to 9.44 percent. This wide range results from large variations in pyritic sulfur between samples. While the pyritic sulfur ranges from 0.20 percent to 7.59 percent, the organic sulfur values all lie in a narrower range,

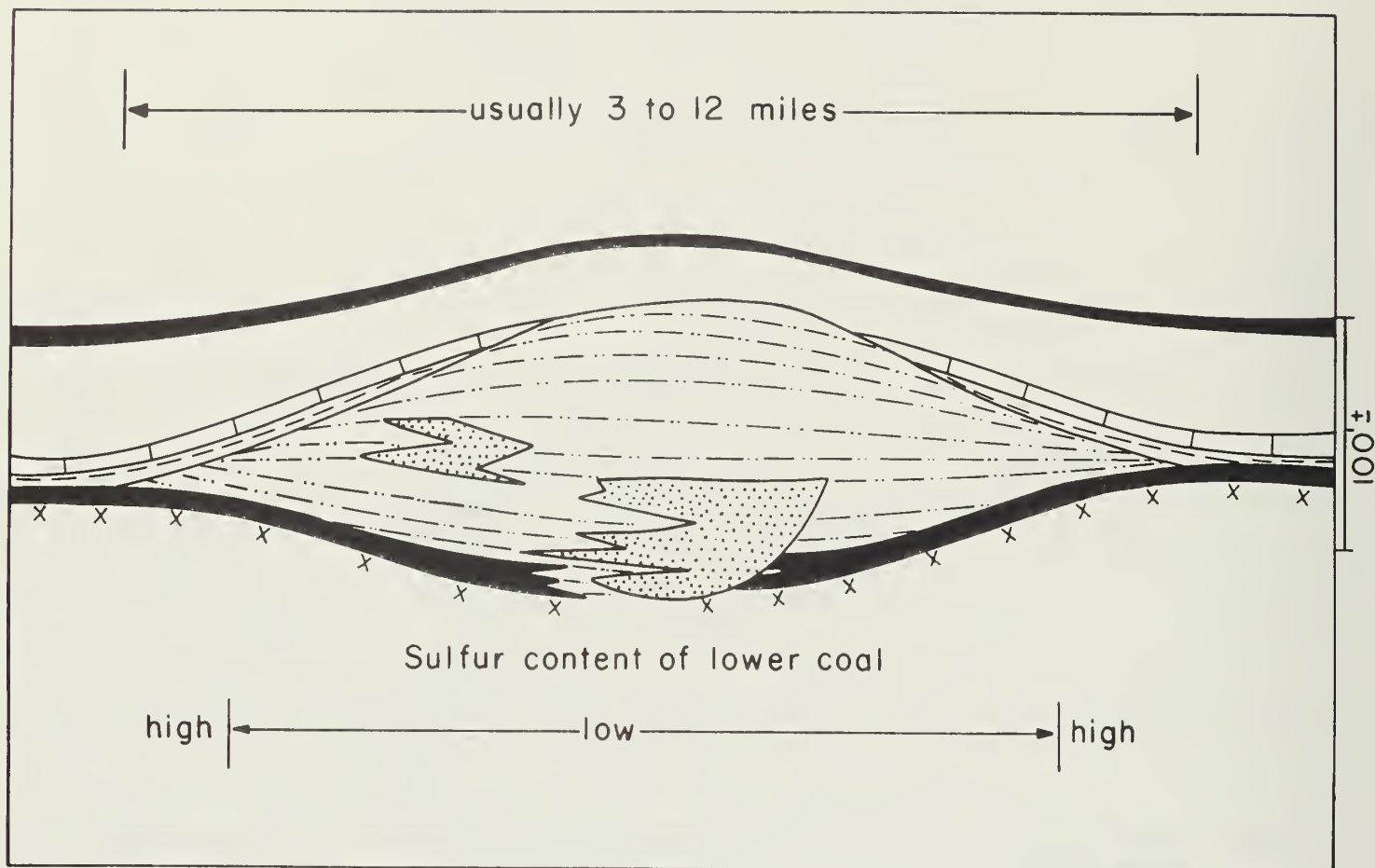


Fig. 3 - Diagrammatic geologic section transverse to elongate lenticular gray shale. Shows pinch-out of black shale and limestone over the gray shale, area of coal missing or split, schematic variation in thickness of the overlying and underlying coals, and relative sulfur content of lower coal.

between 0.50 percent and 2.93 percent. The low-sulfur No. 2 Coal samples were collected from two mines, one in Will County and the other in Woodford County. Since mining has been sparse in Woodford County, it is not possible to delineate the low-sulfur area with any degree of accuracy.

The relationship between the thickness of the overlying gray shale (the Francis Creek Shale Member) and the sulfur content of the Colchester (No. 2) Coal is more complex than that of the Nos. 5 and 6 Coals of southern Illinois. As seen in figure 1 of Smith's article in this Guidebook, extensive areas of Francis Creek Shale are found in a wide area trending southwest-northeast across northern Illinois. Each case of known low-sulfur No. 2 Coal occurs where the shale is well developed (around 50 feet in Will County and perhaps 20 feet in Woodford County, although adequate data on the shale thickness are lacking in the latter area). However, wide areas of high-sulfur coal are also known to occur where the shale is well developed. Data on sulfur content of the coal gathered at the Banner Mine (Hopkins and Nance, this Guidebook, p. 97) do indicate a relationship between the thickness of the Francis Creek and the amount of pyritic sulfur in the coal, but in none of the samples did the total sulfur fall below 2.76 percent (dry basis).

It is quite probable that the sulfur content of the No. 2 Coal is related also to factors other than thickness of the Francis Creek Shale. Johnson and Richardson (this Guidebook, p. 53) indicate different faunas with marine or nonmarine affinities in local areas of Will County. Certain places are known for the abundance of plant fossils in concretions in the Francis Creek Shale and others are known for the abundance of certain types of animal fossils. Data are not presently available to determine if the sulfur in the coal varies with these different facies, but the possibility should be considered. As yet, the geographic distribution of the various facies in the shale over large areas is unknown, but current studies of these facies by Charles Shabica of the University of Chicago

should provide a better understanding of the depositional environments of this shale.

PYRITE VARIATION POSSIBILITY

Stratigraphic variations related to the occurrence of low-sulfur coals in the Illinois Basin suggest a possible mechanism for the observed variations in pyrite content (Hopkins, 1968). As previously mentioned, the gray shale, when present, lies in sharp contact immediately above the coal and the overlying black "slaty" shale. No interbedding of the two lithologies has been observed. It is thought, for the areas studied, that the entire sequence of gray shale and the accompanying channel sandstone were deposited prior to the formation of the black shale. Away from the area of gray shale deposition, the underlying peat was probably exposed to marine waters. Detailed observations of the upper surface of the coal seem to support this hypothesis as there is normally much pyrite and/or apatite concentrated on this wavy surface. Also, a breccia of pyritized, broken shells is frequently found at the contact. The contact of the coal and gray shale is usually sharp and planar.

It is thought, therefore, that the deposition of the gray shale took place at a relatively rapid rate and preceded all, or at least most, of the black shale deposition. During the time of gray shale deposition, the coal in areas closely overlain by black shale was exposed to sea water, taking sulfur from the sulfate ions in the water. Presumably, bacteria were involved in the reduction of the sulfate in sea water and the formation of the initial sulfide minerals. The exact source of the iron is not known, but at least some of it could have been absorbed on clay minerals deposited with the coal. In the adjacent gray shale areas, the coal was rapidly covered by gray muds which sealed it off from access to the sulfate-bearing water. Relations observed in the No. 2 Coal at the Banner Mine (Hopkins and Nance, this Guidebook, p. 97) and in the No. 6 Coal in the one example shown for southern Illinois (fig. 2) indicate a direct correlation between the thickness of the gray shale and the sulfur content, with a gradual decrease in the sulfur as the shale increases in thickness.

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SULFUR CONTENT OF THE COLCHESTER (NO. 2) COAL MEMBER
AT THE BANNER MINE, PEORIA AND FULTON COUNTIES, ILLINOIS

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GEOLOGIC SETTING

Previous studies of sulfur content in Illinois coals (Cady, et al., 1952; Gluskoter and Simon, 1968; Hopkins, 1968; and Gluskoter and Hopkins, this Guidebook, p. 91) have indicated a striking relation between the sulfur content of Illinois coals and the nature of the immediate roof. Significant areas of coal with a sulfur content of less than 2 percent (dry basis) are found only where the coal is overlain by at least 20 feet of silty gray shale, intervening between the coal and the normal roof, which is black shale or limestone (Gluskoter and Hopkins, this Guidebook, fig. 3, p. 6). In the Banner Mine of the United Electric Coal Companies, opportunity was made available to study in detail the relation between the sulfur in the Colchester (No. 2) Coal Member and the thickness of the gray Francis Creek Shale Member of the Carbondale Formation. As shown in the diagrammatic view of the section exposed along the highwall (fig. 5 of the Road Log, this Guidebook, p. 9), the Francis Creek Shale is very lenticular and absent in many places. Where the Francis Creek Shale is missing, the Mecca Quarry Shale Member, a fissile, black "slaty" shale, usually no more than 2 feet thick, is then in contact with the coal. As observed at the mine, the Francis Creek Shale lenses vary from about 100 to 500 feet across, are generally less than 15 feet thick, and appear to be elongate bodies trending in a general east-west direction. Drill hole data were examined but the drilling pattern was not of sufficient density to permit accurate mapping and the determination of the exact trend and lateral persistence of the various lenses.

The undulating upper surface of the coal generally corresponds to the occurrence of the gray shale lenses (fig. 5 of the Road Log, this Guidebook, p. 9), where the shale tends to occupy low places on the coal surface. The origin of this irregularity is unknown, but it affected the localization of the gray mud deposition. Data on the lithologies below the coal are lacking, except for the claystone seatrock, containing carbonized rootlets and numerous slickensides, that have been observed.

COLLECTION OF SAMPLES

Eleven column samples of the No. 2 Coal were collected during the last year and a half under the varying thicknesses of Francis Creek Shale, and 2 samples were obtained where the Mecca Quarry Shale lay immediately on the coal. A column of coal weighing about 25 pounds was picked from the coal exposed in the strip pit, and the overlying shale was measured. In several cases, the coal had to be sampled at distances up to 50 feet away from the highwall where the exact thickness and nature of the shale were not known. The roof material for these samples was assumed to be that observed in the highwall at a point nearest the sample. This assumption appeared to be valid, giving good results in every case, except for sample No. 1 (fig. 1).

The entire coal seam, including any pyrite lenses or nodules, was sampled. The samples were crushed to 3/8-inch top size and caught on a 28 mesh (Tyler) screen; the 28 mesh by zero fraction was discarded. A fraction was split off for chemical analyses of the pyritic, organic, and total sulfur (table 1). Another split was subjected to float-sink analysis, and the coal fraction which floated in

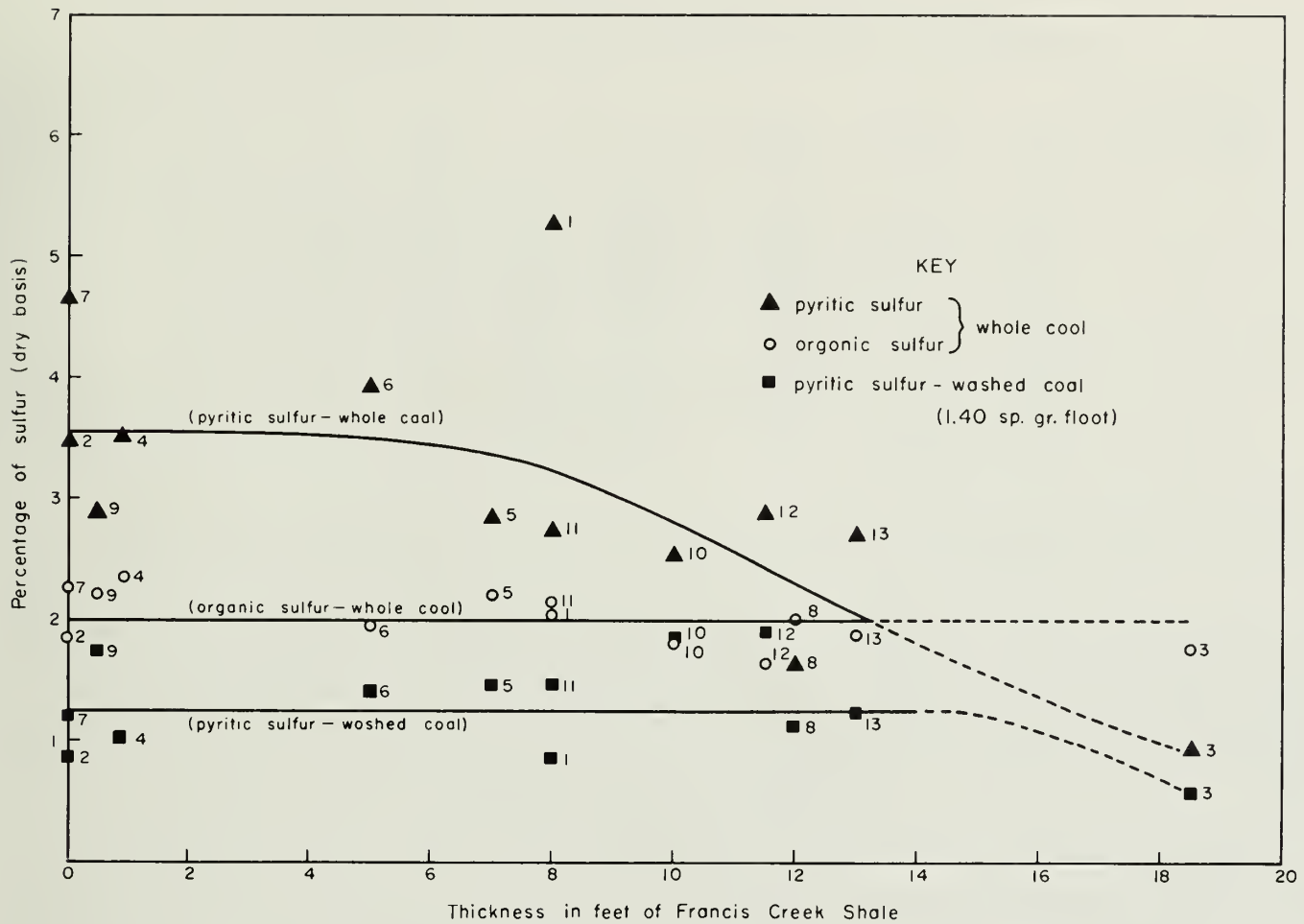


Fig. 1 - Relation of sulfur in the Colchester (No. 2) Coal with thickness of the Francis Creek Shale at the Banner Mine.

a heavy liquid with specific gravity of 1.40 was also analyzed for pyritic and organic sulfur (table 1). Sulfate sulfur was determined, but in all cases, it constituted insignificant quantities.

SULFUR CONTENT

Total sulfur in the 13 samples ranged from 2.76 to 7.34 percent. Nothing was excluded from the samples, although pyrite bodies up to 1 inch thick were encountered. Pyrite, in the form of nodules, lenses, and cleat filling, was observed to be more abundant in the upper foot of the coal. A significant relationship exists between the pyritic sulfur content, which varies from 0.89 to 5.28 percent, and the thickness of the Francis Creek Shale, which ranges from zero up to 13 feet (fig. 1), in the area where samples were collected. As the shale becomes thicker, there is less pyrite in the coal. For sample 3 (fig. 1), the original thickness of the Francis Creek Shale is not known; however, the highwall nearest to the sample showed 5 feet of Francis Creek Shale overlain by unconsolidated Pleistocene terrace material. Because of the low sulfur content of the sample (2.76 percent), it is estimated from figure 3 that the original thickness of the Francis Creek was about 18 or 19 feet. It has also been recognized by mining company personnel (A. H. Seeling, Superintendent, Banner Mine, personal communication) that as the shale became thicker, the preparation plant produced less pyritic reject material. Similar relationships are shown for the Herrin (No. 6) Coal in southern Illinois (Gluskoter and Hopkins, this Guidebook, p. 91).

Both of the curves (fig. 1) for the organic sulfur in the whole coal and the pyritic sulfur of the 1.40 specific gravity float fraction are flat, showing no relation to the thickness of the Francis Creek

TABLE 1 - SULFUR VALUES (DRY BASIS) OF THE 13 COLUMN SAMPLES OF THE COLCHESTER (NO. 2) COAL FROM THE UNITED ELECTRIC COAL COMPANIES' BANNER MINE. VALUES ARE WEIGHT PERCENTAGES.

Column sample no.	Thickness of Francis Creek Shale (ft.)	Whole coal			1.40 sp. gr. float fraction			Change (\pm) following flotation		
		Total	Pyritic	Organic	Total	Pyritic	Organic	Total	Pyritic	Organic
1	8	7.34	5.28	2.02	2.96	0.88	2.07	-4.38	-4.40	+0.05
2	0	5.34	3.49	1.83	2.74	0.87	1.86	-2.60	-2.62	+0.03
3	*5+	2.76	0.89	1.86	2.51	0.56	1.94	-0.25	-0.33	+0.08
4	0.7	5.93	3.51	2.34	3.34	1.00	2.32	-2.59	-2.51	-0.02
5	7	5.11	2.86	2.22	3.71	1.45	2.25	-1.40	-1.41	+0.03
6	5	5.95	3.94	1.92	3.36	1.40	1.90	-2.59	-2.54	-0.02
7	0	6.94	4.63	2.25	3.31	1.22	2.06	-3.63	-3.41	-0.19
8	12	3.65	1.63	2.01	3.14	1.12	2.02	-0.51	-0.51	+0.01
9	0.5	5.13	2.91	2.21	3.94	1.77	2.15	-1.19	-1.14	-0.06
10	10	4.34	2.53	1.79	3.59	1.83	1.74	-0.75	-0.70	-0.05
11	8	4.94	2.74	2.16	3.75	1.46	2.27	-1.19	-1.28	+0.11
12	11.5	4.61	2.89	1.65	3.62	1.90	1.66	-0.99	-0.99	+0.01
13	13	4.61	2.70	1.87	3.08	1.22	1.84	-1.53	-1.48	-0.03
*Entire thickness unknown.										

Shale. The organic sulfur is that sulfur presumably bound to the organic molecules in the coal, and it probably entered the coal at the time of, or shortly after, accumulation; some of this sulfur may have been contributed by plant material. The pyrite in the 1.40 float coal consists mostly of fine-grained particles (Damberger, this Guidebook, p. 99) scattered throughout the coal. These particles are not liberated on grinding, and therefore, not separated by the heavy liquid. This disseminated pyrite has usually been considered syngenetic with coal accumulation.

Thus, the sulfur in the coal, which varies with the thickness of the gray shale, occurs in the form of larger pyrite bodies, such as cleat filling, nodules, and lenses. Some of this pyrite, certainly the cleat filling material, entered the coal subsequent to accumulation; thus, the amount is inversely related to the thickness of the gray shale. This shale may have served as some kind of protective cover limiting the amount of sulfur coming into the coal, by partially sealing off the coal from free access to sea water, the only logical source of the sulfur (SO_4 ions). Either the coal in the areas where the shale is the thickest was covered earlier, or the thicker shale may have provided a more effective seal.

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PETROGRAPHIC CHARACTER OF THE COLCHESTER (NO. 2)
COAL MEMBER AT THE BANNER MINE, PEORIA AND
FULTON COUNTIES, ILLINOIS

Heinz H. Damberger
(Illinois State Geological Survey)

The thickness of the Colchester (No. 2) Coal Member of the Carbondale Formation in the vicinity of the Banner Mine ranges from 20 to 36 inches and normally varies between 28 and 34 inches (fig. 1). Macroscopically, the coal has a uniform appearance; only 1 thin, fairly consistent shaly band has been recognized. This band, where present, occurs about 4 inches above the base of the coal, is $\frac{1}{2}$ to 2 inches thick, dark brownish-gray in color, and highly carbonaceous.

Most of the seam is made up of finely laminated clarain; fusain partings are common, and thick vitrain bands are rare. Pyrite nodules and pyrite as secondary cleat filling are more common in the upper one-third of the seam. Authigenic calcite, which occurs in cleats, is frequent in the middle, but is less common in the upper and lower parts of the coal.

An argillaceous band has been observed in some places a few inches below the top of the seam. It is up to $1\frac{1}{2}$ inches thick and generally consists of thin, discontinuous shaly lenses. This is apparently the band where W. H. Smith of the Illinois State Geological Survey recently found coal balls in this area. Above the coal balls, but within the coal, are 2 thin shale lenses which contain marine fossils, including pyritized shells of the brachiopod Mesolobus (plate 8, fig. 2).

Two column samples were polished for a more detailed study of the petrographic makeup of the No. 2 Coal from the Banner Mine. One column was taken from the southeastern part of the pit where black shale normally rests directly on the coal. The other was taken in the northwestern part of the pit under about 8 feet of gray Francis Creek Shale. The first column is shown in plate 9. Also included in plate 9 were photomicrographs of some of the typical layers. The second sample is not illustrated.

Small (10-30 micrometers) disseminated grains of syngenetic pyrite are especially abundant in the upper few inches of the coal, but also are found in several other layers. The grains show a preference for bedding planes and the boundaries of vitrinite laminae (plate 9A).

The bedding is very regular throughout most of the seam, especially in the layers that are rich in syngenetic pyrite. Local disturbances of the regular bedding occur around particles of fusinite, semifusinite, fusinized resinite, corpovitrinite, and sclerotinite. Such local disturbances smooth out within a short lateral and vertical distance from the rigid particle that causes the disturbance. Vitrinite- and exinite- rich laminae bend around rigid particles without breaking and usually without thinning.

Microscopic examination reveals that most of the seam is made up of degraded plant fragments; leaves and spores predominate among the identifiable plant fragments. Spore exines, cuticles, resins, and waxes, which are common constituents of the coal and are most resistant to decomposition, usually have a highly corroded appearance. Woody material can be recognized in the fusinites and semifusinites which are dispersed in the coal or concentrated in lenticular fusain layers. If vitrinite represents, in part, gelified woody material, it seems to have been of a small size.

The coal balls found in the Banner Mine contain a large amount of pyrite. The internal structure of the coal balls is strikingly different from that of the surrounding coal. While the coal generally is micro-laminated, the coal balls show only faint indications of bedding. The laminae of the coal do

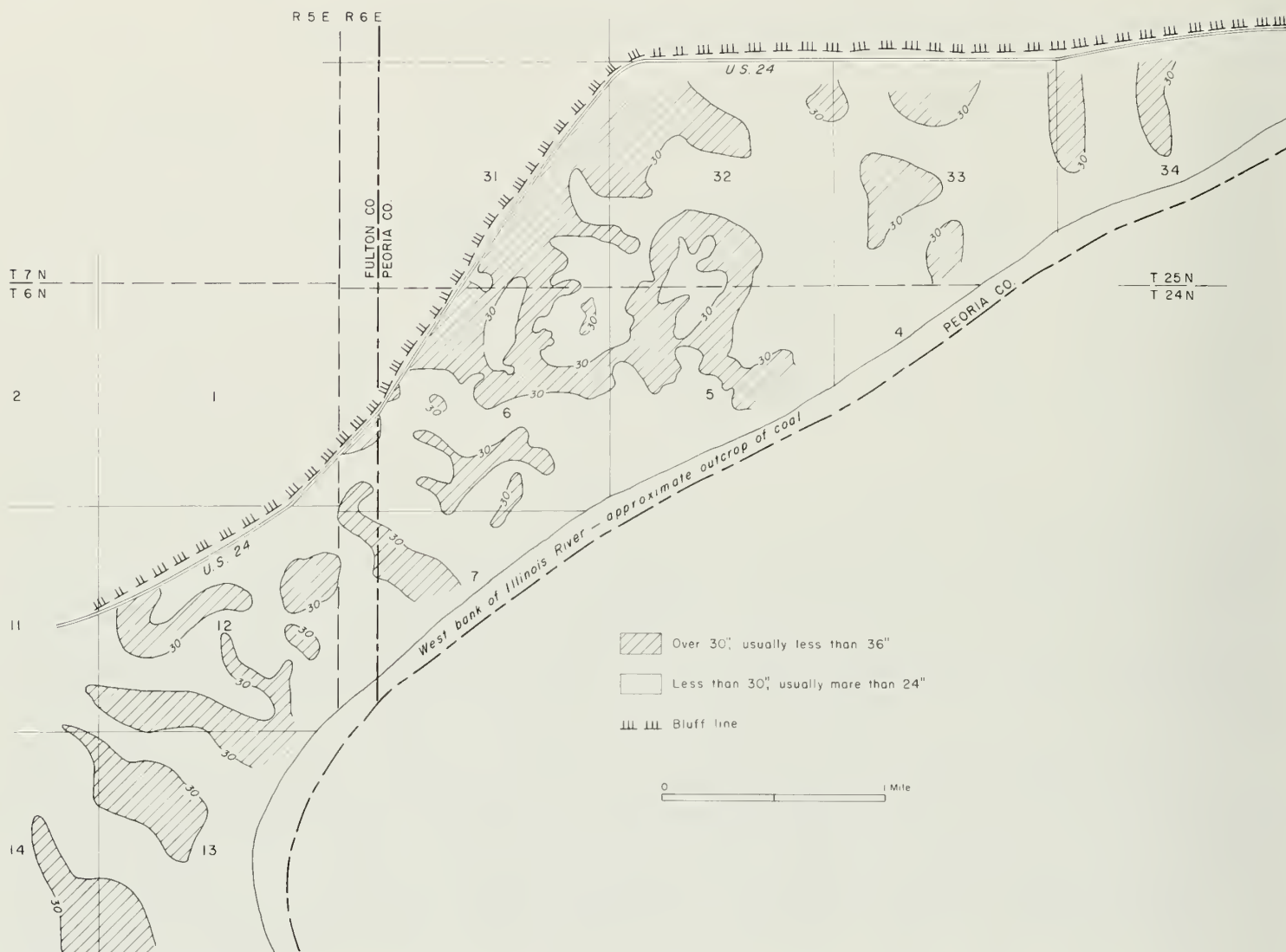
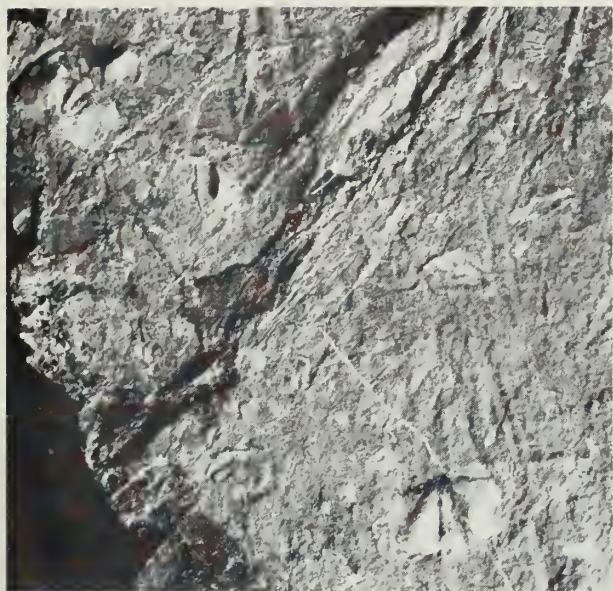


Fig. 1 - Sketch map showing thickness of the Colchester (No. 2) Coal from closely-spaced drilling in the Banner Mine area (prepared by W. A. Olsson from data provided by United Electric Coal Companies).

not seem to continue into the coal balls, but rather bend around them. Even very thin vitrain laminae can be followed continuously under or above coal balls (plate 8, fig. 4). Coal layers above usually are affected more by the presence of the coal ball than layers below. If the surface of the coal balls is irregular, disturbance in the micro-lamination of the coal directly above may result.

A yellowish-brown calcareous phosphate layer up to 2 inches thick occurs at the top of the coal seam where it is overlain by the black Mecca Quarry Shale. The contact with the coal is sharp, but irregular, and is characterized by patches of pyritized plant material showing disturbed bedding. The laminae of the coal near the contact generally follow the irregularities of the base of the phosphatic layer. However, sharp downward protrusions into the coal cause a thinning or disruption of coal laminae. Small, calcite-filled fissures are common in the coal at such protrusions. The prominent protrusion of the phosphatic layer in figure 5 of plate 8 is apparently caused by a gastropod. Small fragments of mineralized wood and pyrite are also fairly common in this layer. The base of the overlying black shale is characterized by phosphate lenses or nodules, streaks of black shale, and pyrite (plate 8, fig. 5).

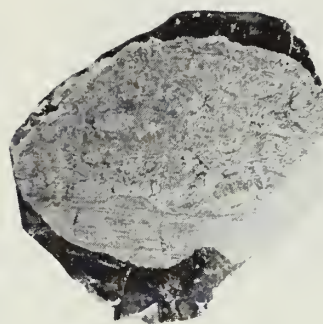
The phosphatic layer is missing where the gray Francis Creek Shale overlies the coal. Instead, a pyritic layer about 1 inch thick is generally found between the coal and the gray shale. This layer is well bedded and may grade downward into highly pyritized, well laminated coal.



2

1 cm

Fig. 2—Pyritized *Mesolobus* specimens in a shaly streak within the Colchester (No. 2) Coal, occurring a few inches below a highly pyritized coal ball (see fig. 3).



3

5 cm

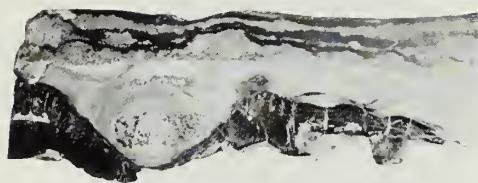
Fig. 3—Polished coal ball with plant structures, highly pyritized.



4

5 cm

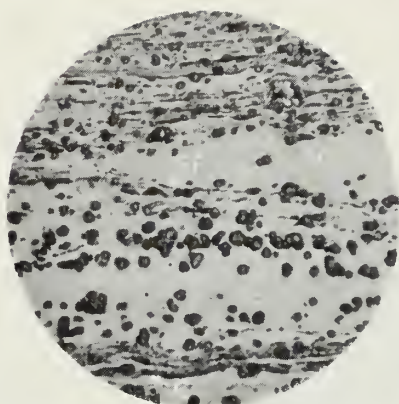
Fig. 4—Polished coal sample with coal balls of different sizes. The lamination in the coal circles the coal balls. Some disturbance of the laminae at coal balls can also be observed. The internal structure of the coal balls is strikingly different from that of the coal.



5

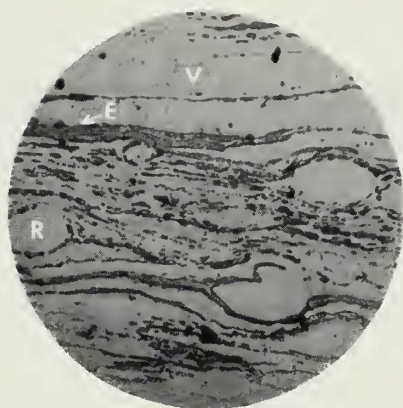
5 cm

Fig. 5 - Polished specimen of the phosphatic layer at top of No. 2 Coal showing the outlines of a gastropod at the base of a protrusion of the phosphatic layer into the coal. Note the thinning of the coal laminae as they approach the phosphatic hump. Some streaks of black shale are visible at the top of the specimen.

A

(A)

Vitrinite (V) interbedded with cutinite (C) and sporinite (SP). Many small syngenetic pyrite aggregates (10 to 30 μ m) tend to be concentrated along bedding planes

B

Oval resinlike bodies (R), associated with vitrinite (V) and exinite (E)

(1)

0 to 7.3 cm
Clarain, finely laminated with much disseminated pyrite.

(2)

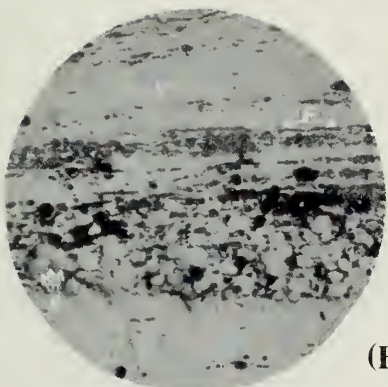
7.3 to 9.6 cm
Clarain, similar to (1), but with much less syngenetic pyrite.

(3)

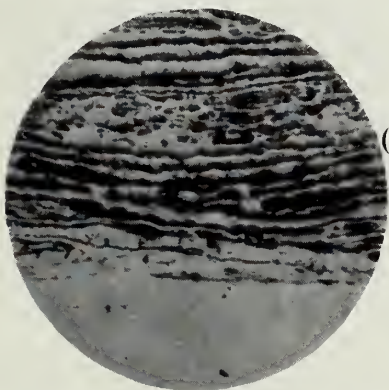
9.6 to 18.2 cm
Clarain, similar to (1), in part contains more syngenetic pyrite.

(4)

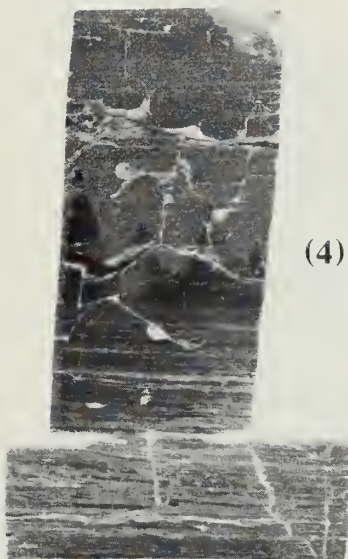
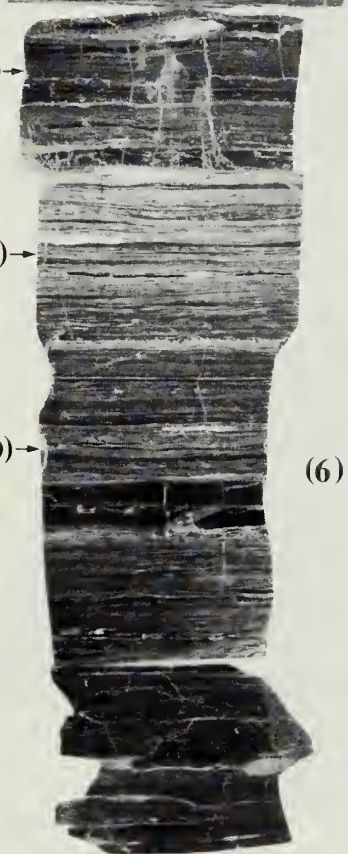
18.2 to 29.4 cm
Clarain, similar to (1), but almost free of visible pyrite, some vitrain layers up to 5 mm thick.

C

Vitrinite laminae (V), many small resin bodies (R), some syngenetic pyrite and relatively small amounts of exinite (E) (fragmented cutinite and sporinite)

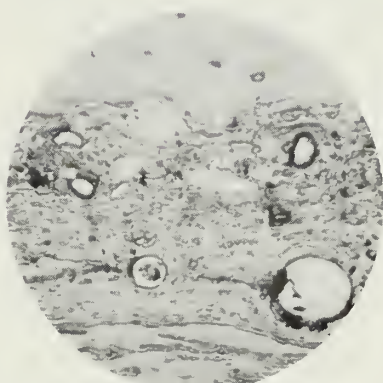
D

High proportion of cutinite above vitrinite, also a little syngenetic pyrite

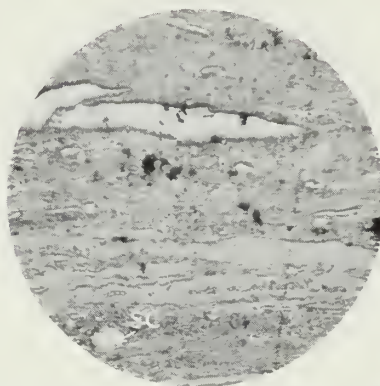
(4)**(5)****(B)****(C)****(D)****(6)**

29.4 to 30.1 cm
Fusain, lenticular in clarain, thin shaly interlaminae.

30.1 to 43.3 cm
Clarain with small fusain lenses (prominent fusain parting at 40.0 cm), 7 mm vitrain layer at 37.4 cm, little syngenetic pyrite seen.

E

Fine-grained exinite (mostly fragmented sporinite and cutinite); some sclerotinite (SC)

F

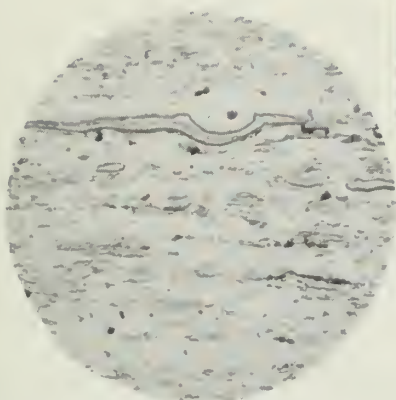
Matrix of fine-grained exinite and vitrinite in which vitrinite occurs as irregular sheets. Sclerotinite (SC) and semifusinite (SF)

(6)**(7)**

43.3 to 44.3 cm
Fusain rich layer, clarain and fusain irregularly interlaminated.

(8)

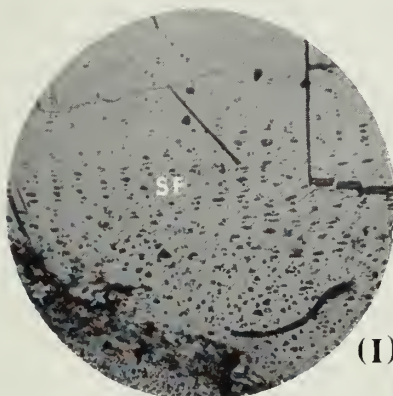
44.3 to 66.2 cm
Clarain with many fusain lenses and partings, some vitrain laminae, a little fine-grained syngenetic pyrite more abundant along bedding planes, especially near base.

G

Lamination is well displayed by small-sized (darker) exinite in a matrix of vitrinite with some thin vitrinite laminae

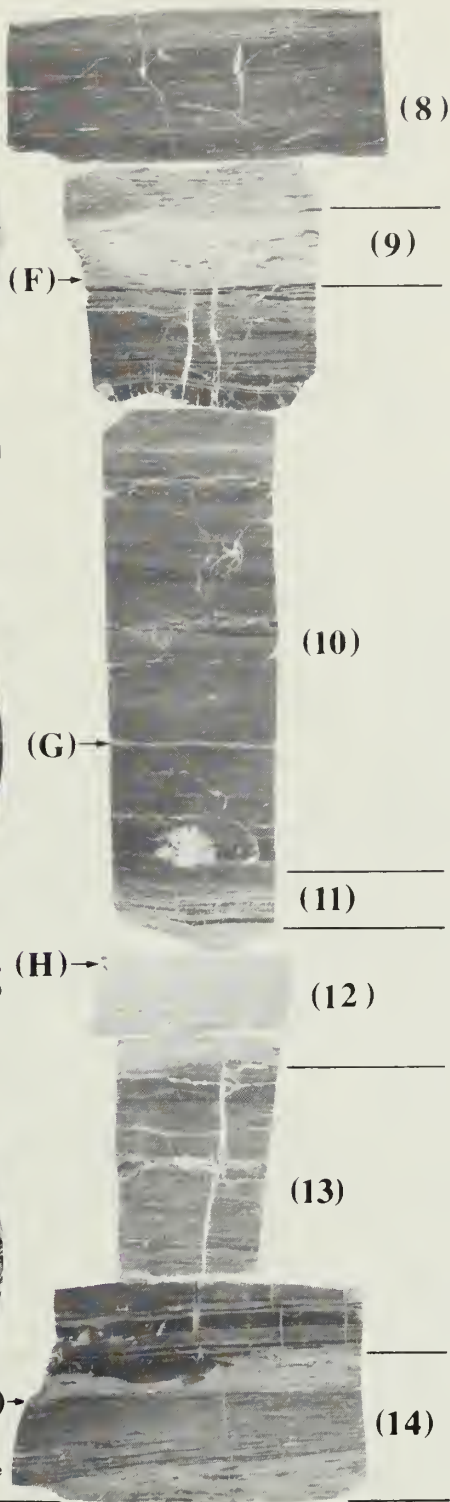
H

Shale with disseminated small coal fragments (mainly vitrinite) and a vitrinite band with two small displacements

I

Semifusinite (SF) trending toward vitrinite (top) and toward fusinite (bottom)

BASE OF COAL SEAM, SHARP CONTACT WITH UNDERCLAY

**(8)****(9)****(F)**→**(10)****(G)**→**(11)****(12)****(13)****(14)**

66.2 to 67.2

Dull coal, irregular fragments of fusain and vitrain in a fine grained matrix.

67.2 to 76.2 cm

Clarain, finely laminated, several vitrain bands up to 6 mm thick, little syngenetic pyrite seen.

76.2 to 76.8 cm

Clarain, much syngenetic pyrite.

76.8 to 79.0 cm

Shale, dark brown, with vitrain and fusain fragments throughout, more fusain at base.

79.0 to 84.3 cm

Clarain, finely laminated, thin vitrain laminae more prominent near base.

84.3 to 86.4 cm

Clarain, rich in fusain and exinitic material, somewhat shaly near base, much fusain in basal laminae.

Plate 9 - Polished column sample of Colchester (No. 2) Coal, Banner Mine. Column approximately natural size, diameter of photomicrographs about 1 millimeter. Photomicrographs taken with 5.6x dry objective, 10x ocular, some photos taken with partly crossed polarizers to increase contrast.

THE LA SALLE ANTICLINAL BELT IN ILLINOIS

Kenneth E. Clegg
(Illinois State Geological Survey)

INTRODUCTION

The presence of a major northwest-southeast trending anticlinal structure through the east half of Illinois has been known for more than one hundred years. It was reported in literature at least as early as 1866 when Worthen described the approximate location and trend of the La Salle Anticline in the La Salle area. He discussed the difference in elevation of the "coal measures" from a depth of three or four hundred feet on the west side of the fold up to the ground surface at its crest and pointed out that this relationship indicated folding had taken place after deposition of the coal. Worthen either failed to notice or did not mention the structural unconformity visible in the north bluffs of the Illinois River Valley. Freeman (1868) described the "coal measures" as resting directly on the St. Peter Sandstone and mentioned that the southwestward dip of the St. Peter was greater than that of the coal. The southern extent of the La Salle Anticline seems not to have been suspected at that time.

In 1875, Freeman discussed its continuation southeastward into Livingston County with its axis a little east of the Vermilion River. Worthen (1890), on the basis of a diamond drill boring at Tuscola in Douglas County, showed that the structure extended at least that far southeast, and speculated that if it continued far enough, it would cross from Illinois into Indiana near Vincennes. With the discovery and development of oil fields in Clark and Crawford counties, the presence of the fold was further documented there. By this time, the La Salle Anticline was recognized as being more complex than a simple asymmetrical anticline. Cady (1920) made a complete résumé of earlier work, and, with the aid of numerous sketches, cross sections and structure maps, showed the complete extent of the structure in Illinois, as many of the subsidiary structures as were known at that time, and the relation of the entire complex with other major structural features of the state.

With the discovery of deeper oil in the Fairfield Basin, and more recent intensive search for gas storage structures in north central Illinois, the anticline's complex nature is being more fully revealed. Based on present knowledge, the structure appears to be, and thus is called an "anticlinal belt," consisting of an echelon north-south trending folds and troughs. Numerous domal structures, such as those at Ashmore, Brocton, Mahomet, Pontiac, and Ancona are also now known to constitute parts of the complex structural belt. The domes at Ancona and Pontiac in Livingston County have recently been identified and outlined as a result of the search for underground gas storage facilities. More recently, a pronounced monoclinal fold, here called the Osman Monocline, and a broad synclinal fold, here named the Colfax Syncline, have been delineated in eastern McLean and northeastern Piatt counties (fig. 1). There seems to be little doubt that other structural components will be discovered, especially along the northern part of the trend, if and when more drilling is done along those areas where subsurface information is sparse or non-existent.

STRUCTURE

Figure 1 shows the location of the La Salle Anticlinal Belt in Illinois, the location of some of the structural components that make up the entire complex, and the relation of the structural trend to other major structures of the state. Steeply dipping beds are known to be present in La Salle County, along part of the east edge of McLean County, and in southern Douglas and northern Coles counties.

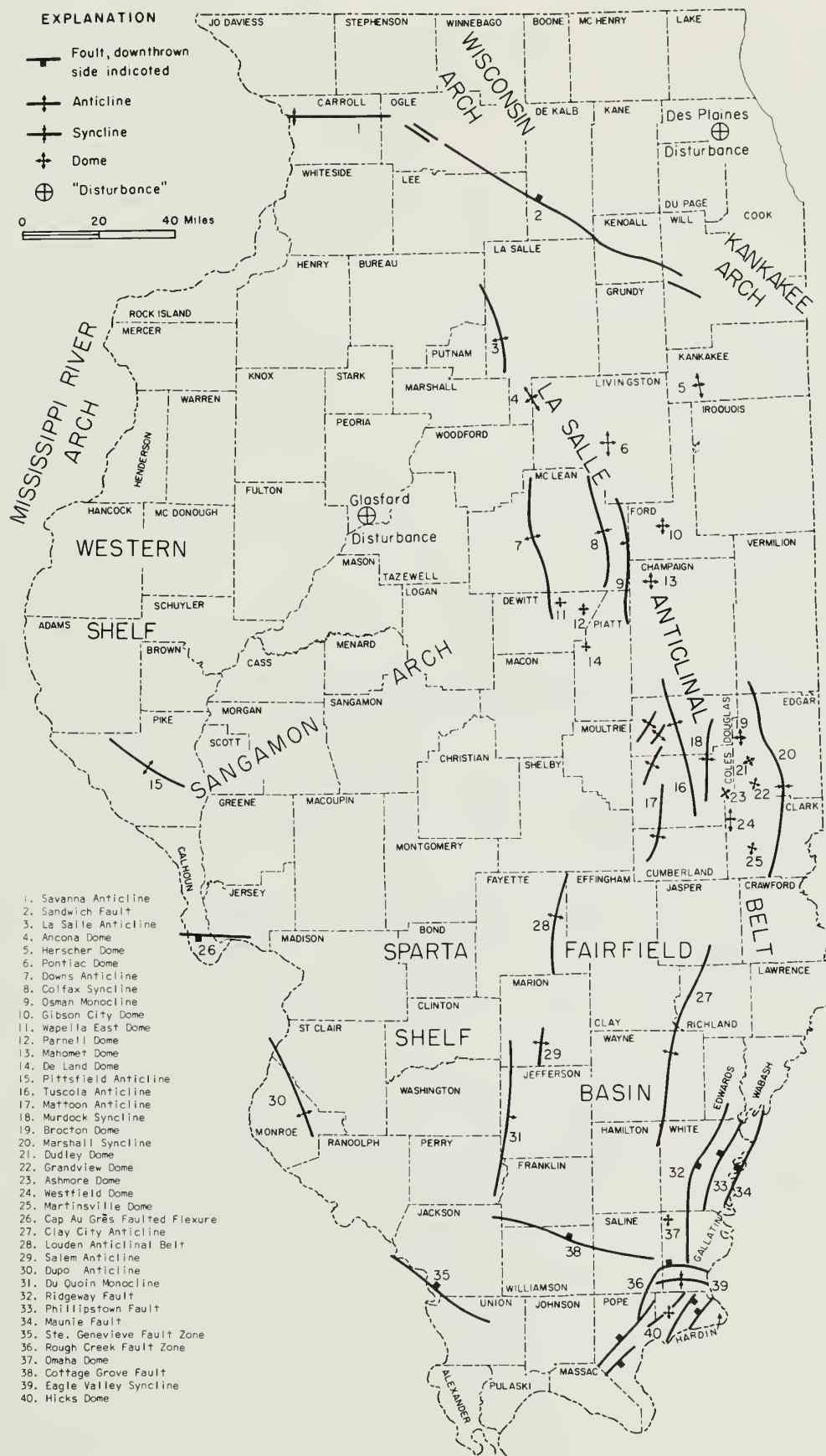


Fig. 1 - Structural features of Illinois.

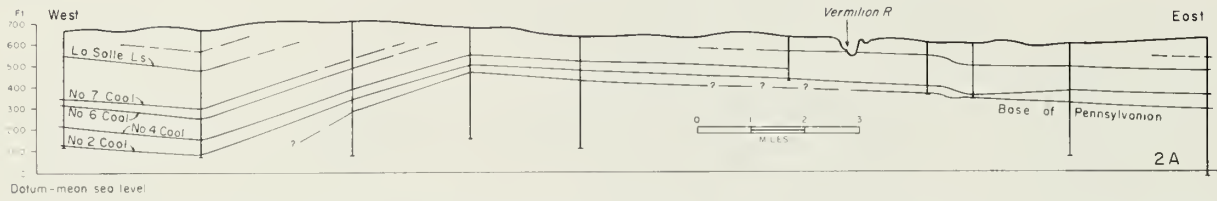


Fig. 2A - East-west structure section across the La Salle Anticline, La Salle County.

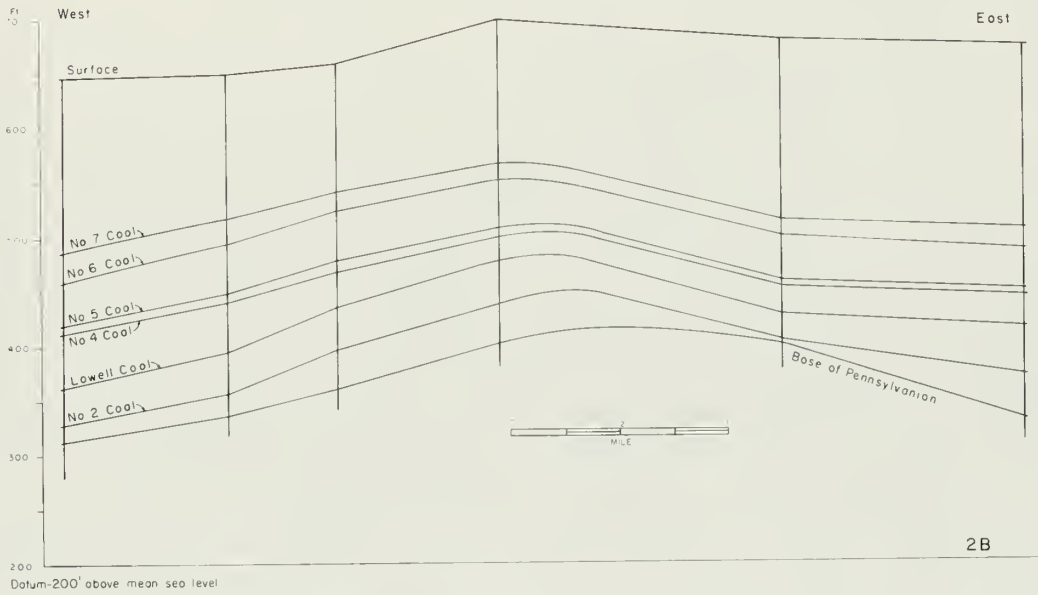


Fig. 2B - East-west structure section across the Pontiac Dome, Livingston County.

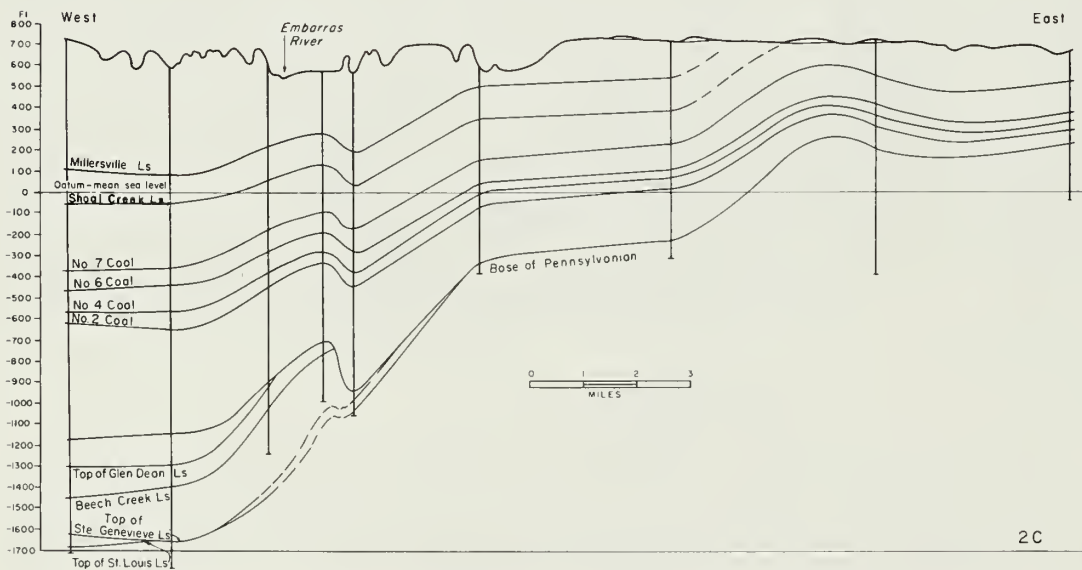
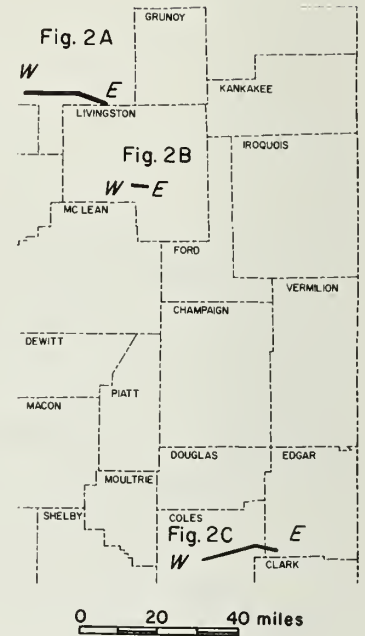


Fig. 2C - East-west structure section across the La Salle Anticline, Coles and Edgar counties.

Whether subsidiary folds and domes are as abundant east of the crest of the fold between La Salle and Douglas counties as they are in the Douglas-Coles county area is not yet known. Their presence in Douglas and Coles counties is known because of extensive petroleum exploration.

South of Coles County, the overall structure of the folded belt is more gentle and monoclinal in nature, and roughly defines the eastern boundary of the Fairfield Basin. The Colchester (No. 2) Coal Member of the Carbondale Formation (Pennsylvanian), in the vicinity of Oglesby in La Salle County, rises about 500 feet within a distance of 1 mile from west to east over the crest of the anticline. An elevational difference of 950 feet over a similar distance exists east of Charleston in Coles County. In southern Lawrence County, the coal rises no more than about 300 feet over a 5- or 6-mile distance across the steepest part of the fold. Figures 2A, 2B, and 2C are structural cross sections across part or all of the anticlinal belt south of La Salle, at Pontiac, and near Charleston, respectively. Comparison of figures 2A and 2C, which are drawn to the same horizontal and vertical scale, reveal the greater vertical uplift that has taken place along the south part of the folded belt. Figure 2C also illustrates the occurrence of pre-Pennsylvanian folding. While the folding is known to have occurred also in the vicinity of La Salle (Cady, 1920), the data used in the cross section did not extend deep enough for it to be shown.

Figure 2B, an east-west section across the Pontiac Dome, shows local differential movement that occurred during deposition of the lower strata of the Carbondale Formation. Detailed study along the structural trend in east-central Illinois has shown similar variations (Clegg, 1965).

STRUCTURAL HISTORY

The structural history of the La Salle Anticlinal Belt is not yet fully known. It appears to have developed over a long period of geologic time with deformation proceeding relatively rapidly at some times and more slowly at others. There seems also to be evidence that deformation took place along different parts of the structural trend at different times.

Cady (1920) reported that deformation began in the La Salle area during Ordovician time prior to deposition of the St. Peter Sandstone. He also reported slight deformation during or after deposition of the St. Peter, some time after Silurian and probably after Devonian, and during and after Pennsylvanian time.

Payne (1939), in a study of the age of the La Salle Anticlinal Belt, concluded that "...initial deformation took place in post-Chesterian pre-Pennsylvanian time, and that the area of maximum deformation moved progressively southward from the La Salle area, with the maximum differential elevation occurring in the first pre-Pennsylvanian movement in La Salle and Douglas counties, and after Pennsylvanian deposition had begun in Lawrence and Wabash counties."

Siever (1951) demonstrated that the sedimentary basin, of which southern Illinois is a part, began to form at least as early as Canadian (lower Ordovician) time and, with minor interruptions, this development continued at least until late Pennsylvanian time. He further reported that flexing along the anticline began early in the Mississippian with further slight folding during deposition of Chesterian sediments. He described a period of strong folding that occurred after cessation of Mississippian sedimentation, which was followed by a long period of erosion and peneplanation. Another period of uplift was followed by erosion, producing deep incisions of the elevated surface where the earliest Pennsylvanian sediments were then deposited.

By means of an isopach map of the Carbondale Formation and a series of stratigraphic and structural cross sections, Clegg (1965) demonstrated progressive but relatively minor movement along the anticline in central Coles County throughout Pennsylvanian time, extending at least through the time of deposition of the Bond Formation sediments. Intensive deformation of all Pennsylvanian strata in that area showed that a period of relatively strong folding took place either in late or post-Pennsylvanian time. In Coles County there is a difference of elevation of at least 1000 feet in the Colchester (No. 2) Coal. Clegg's study showed that the structural movement following deposition of Colchester (No. 2) Coal was less than half of the total deformation that has taken place in this area.

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CLASTIC DIKES AND RELATED IMPURITIES IN HERRIN (NO. 6)
AND SPRINGFIELD (NO. 5) COALS OF THE ILLINOIS BASIN

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(Illinois State Geological Survey)

INTRODUCTION

Clastic dikes and veins exhibit considerable variability in size, shape, attitude, and composition. They may occur in any kind of host rock, and the material which fills the cracks may be almost any kind of sediment. The Herrin (No. 6) and Springfield (No. 5) Coal Members of the Carbondale Formation of the Pennsylvanian are greatly affected by this type of disturbance in north central and western Illinois. Though clastic dikes (frequently called "horsebacks") have been observed in almost every coal seam of the Pennsylvanian in Illinois, no further reference will be made to these relatively minor disturbances in other coals.

HERRIN (NO. 6) COAL MEMBER

The clastic dikes and "white tops" in No. 6 Coal, which greatly influence the quality of the coal, are generally restricted to the northwestern part of the coal field. Several characteristic features discussed below usually occur together.

Convergences Within the Coal Seam

Portions of the clastic dikes frequently protrude horizontally into the seam for distances up to about 3 feet. The layers of the coal bend toward the protrusion from both above and below, forming a local discordance against the protrusion or against the dike itself (plate 10, fig. 1). Attempts to reconstruct to the original horizontal bedding indicate that a piece of coal is now missing at the position of the protrusion (plate 10, fig. 2). Since the layers of the coal bend down and up toward protrusions without any sign of breaking, the crack must have been formed early when the seam material was still plastic. The fact that the sediments directly above the No. 6 Coal are not usually affected by the disturbance supports this conclusion.

Fan-like Spreading of Coal Laminae and
Interfingering with Fine Clay Laminae

Frequently, a fan-like spreading of the coal laminae adjacent to a clay dike can be observed in the hanging dike wall if it is curved (plate 11, fig. 3). Thin layers of material similar to that filling the dike intrude 4 to 8 inches into the coal. The clay laminae thin away from the clastic dike. It follows the bedding planes in the coal.

PLATES 10 AND 11

Figure

1. Layers of the coal converge toward a protrusion from a clay dike in No. 6 Coal, Peabody Coal Company, Edwards Mine, Peoria County.
2. A clay dike in No. 6 Coal (a) and reconstruction to original horizontal bedding (b). A block of coal of the size of the area, stippled or possibly somewhat smaller (due to horizontal displacement of the side walls of the crack), is missing at the position of the clastic dike. It is assumed that this seam material was ejected during an earthquake when the crack was formed.
3. Fan-like spreading of the coal laminae in No. 6 Coal in the hanging wall of a clay dike at the top of the coal. Thin laminae of dike filling intruded 4 to 8 inches (10 to 20 cm) into the coal, predominantly along bedding planes.
4. Irregularly layered "white top" material at the top of No. 6 Coal. Light gray clay with coal fragments, coal below is heavily disturbed by slips and cracks which are all filled with at least a film of the light gray clay. The lower part of the relatively undisturbed coal is not visible.



1



2b



3



4

Intense Disturbance of the Top of the No. 6 Coal

The top layers of the seam are most heavily disturbed. A layer of light gray clay up to 3 feet thick, containing irregularly intermixed coal fragments, is found in many places (plate 11, fig. 4). The amount of clay decreases downward until the bedding becomes visible in the coal seam below. The coal under such "white top" material reveals abundant irregular cracks which are filled with the same light gray clay. These cracks have all dimensions from about 3 feet wide to knife-edge thickness. But even the thinnest fissures are filled with a film of the light gray clay that is typically associated with the "white top" type of disturbance of No. 6 Coal (fig. 5). The thickness of the "white top" material is quite variable even within relatively restricted areas.

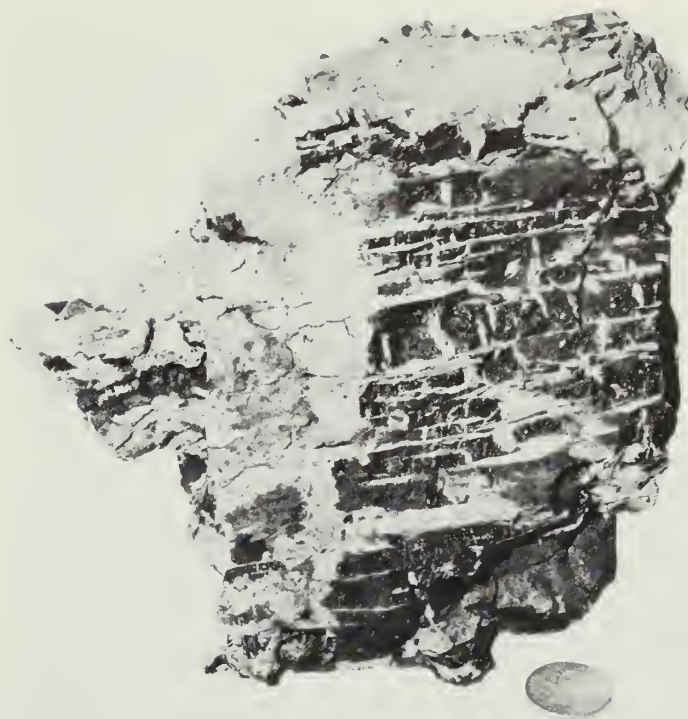


Fig. 5 - Sample from much disturbed upper part of No. 6 Coal.

Irregular Erosion of the Top Layers of No. 6 Coal

The top of No. 6 Coal is irregular throughout the northwestern part of the coal field. Depressions occur where the top part of the coal is heavily disturbed and where clay dikes and veins occur in random directions. Close examination shows that the seam was originally deposited in approximately equal thickness throughout, and that only after deposition was part of it removed from the top, so that the remaining thickness of the coal varies up to 6 feet. The distance between depressions is 60 to 180 feet (20 to 60 meters). The removal occurred before the roof sediments were deposited, as they are normally undisturbed.

Microscopic observations show that the coal had, at the time of the disturbance, already advanced to a state of high gelification. The gel (now vitrinite) was capable of viscous flow toward zones of lower pressure (cracks). The vitrinite layers were already fully developed as gel layers close to their present thickness. Many small disturbances of the same type as convergences can be observed along the coal-dike filling boundary.

Interpretation of Observations

The combination of features in the heavily disturbed No. 6 Coal are interpreted as being the result of a powerful earthquake and seismic sea waves. The seam material failed in many places throughout northwestern Illinois, causing irregular cracks and fissures to develop. Ground failure and the formation of cracks in relatively unconsolidated sediments are well known phenomena in connection with large earthquakes. Fragments of seam material were apparently ripped out of the walls of the cracks as they opened up and were ejected together with the water that filled the cracks. Examples of such eruptions have often been observed during earthquakes, as in the recent Alaskan earthquake (Foster and Karlstrom, 1967). The convergences within the seam are considered to be the result of removal of material from the walls of the freshly opened cracks.

The upper layers of the seam, in particular, were loosened and disturbed both by earth movements and seismic sea waves, which carved away much of the loose material. Seam material intermixed with stirred-up mud, then settled as "white top." The well bedded seam material along the rims of the fissures was lifted up, and individual layers became separated from each other, allowing the infiltration of fine clay along separation planes. This behavior was confined to the upper part of the seam where upward movement was not restricted by overlying sediments.

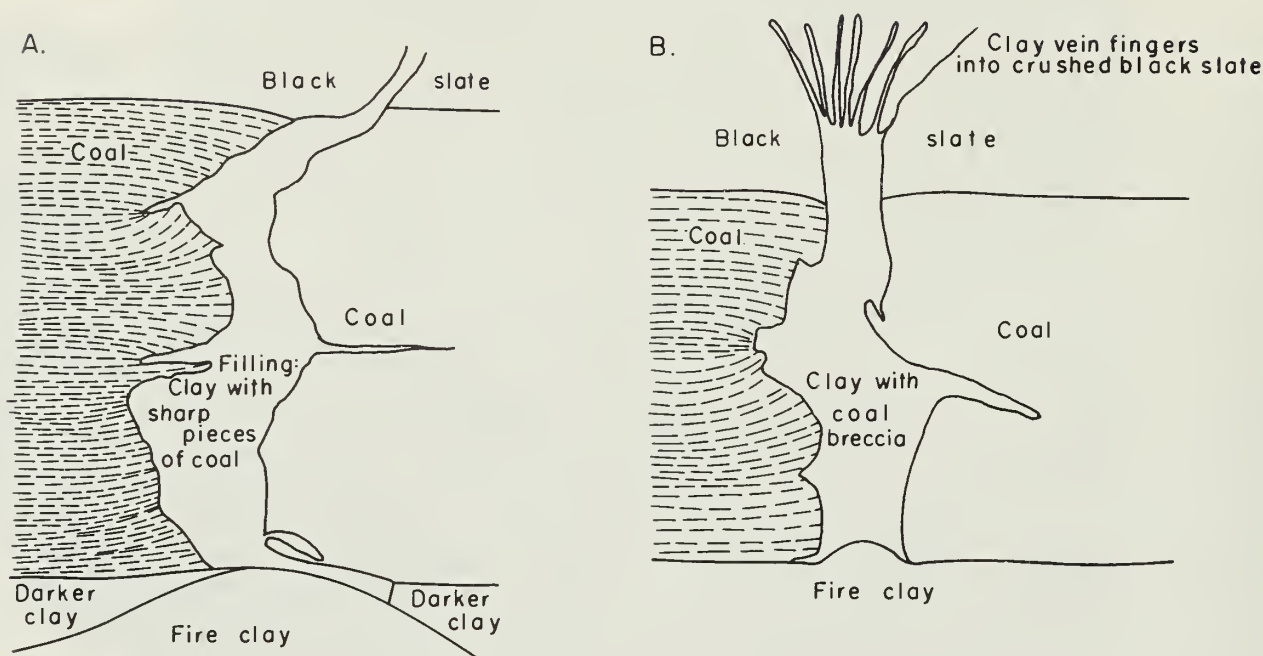


Fig. 6 - Two drawings from 1912 mine notes of K. D. White showing the important characteristics of clastic dikes in No. 5 Coal (Menard and Tazewell Counties).

SPRINGFIELD (NO. 5) COAL MEMBER

Clastic dikes in Springfield (No. 5) Coal occur about 70 feet (about 20 meters) below No. 6 Coal in northwestern Illinois. The No. 5 Coal differs from No. 6 in that there is no variation in coal thickness, there is no "white top" material anywhere near the top of the coal, and there are no inter-laminations between coal and dike filling. Convergences within the seam, similar to those described in No. 6 Coal, are present, but are generally much smaller. K. D. White (1912) made accurate drawings during his visits to mines (fig. 6). All characteristics of clastic dikes in No. 5 Coal observed in the present study can be seen in his sketches: the continuation of the dike into the roof shale, the internal convergences at dike protrusions into the coal, the downward bending of the layers of the hanging wall or in both sides if the dike is vertical, the upward bulging of the under-clay below the dike, and the spreading of the dike filling along the base of the coal seam.

The cracks in No. 5 Coal were formed after the sediments above the coal seam had accumulated, but were not confined to the coal alone. Figure 7 is a photo that was taken only a few hours after a large roof fall had occurred in the mine entry at the El-B Mine, Logan County, at the location of the clay dike. The shape of the clastic dike is characteristic; there is a well defined stem up to about 3 feet (1 meter) above the coal where the clay dike branches to both sides. A little higher, the clay-filled branches reunite at the St. David Limestone Member to a well defined single dike, only to split again further up. From there, the cracks and slips are no longer filled with any appreciable amount of clastic material. Movements are indicated by polished and slickensided slip planes that extend higher where they gradually die out.

These features are interpreted as being due to a severe earthquake that occurred when 20 to 30 feet (6 to about 10 meters) of sediments (present thickness) had already been deposited on top of the No. 5 seam. The cracks that formed during the earthquake seem to have originated at the coal/roof shale level, because many small cracks are confined to within a few feet of both sides of this position. The cracks must have remained open for a while as far up as the St. David Limestone. Apparently, the muddy sediments were consolidated enough to support open cracks to that point. Higher up, the mud was still in a plastic state and much slipping occurred but no open cracks formed. The filling material was derived from the side walls of the cracks and from the unconsolidated material above (clay mineral analyses support this conclusion). While pieces of black roof shale are found in the dike within the coal, pieces of coal have never been observed above the top of the coal. It

appears that the dike filling gradually seeped down through the fissures and around blocks of black shale and coal without force or pressure.

DISCUSSION OF PREVIOUS INTERPRETATIONS

Important literature discussions on clastic dikes have been presented by Diller (1890), Shrock (1948), and Strauch (1966).

Clastic dikes are very widespread in the Pennsylvanian of the North American continent, but relatively few reports are known from the European coal fields. In the Appalachian coal field, a number of coal seams are affected by clastic dikes. Those which the author observed in the Pittsburgh Coal west of Pittsburgh and in southern Pennsylvania are similar to those in the Illinois No. 5 Coal. Gresley's (1898) descriptions of clay veins in several Appalachian coal seams correspond with descriptions of clastic dikes in the Illinois No. 5 Coal. He concluded that clastic dikes, in all probability, are earthquake-related phenomena. Crane (1898) reached a similar conclusion.

Orton (1884) and Ashley (1899) imply an early diagenetic formation of the clastic dikes without further discussing their origin. Savage (1910) concludes that clastic dikes cannot be formed during earthquakes because they "... would not be limited to a few feet in vertical height, or to a particular coal seam." He relates the cracking to volume loss during the coalification process, which built up strain within the seam, resulting in fissuring. Clay from above then was forced down into the fissures. Savage's conclusions are supported by Bain (1895). However, it is difficult to understand that only some coal seams would be affected by this and not others and how the difference in the type of disturbance between Illinois No. 5 and No. 6 Coals should have developed. Price (1933) saw the formation of clastic dikes in connection with the Appalachian revolution as a purely tectonic phenomenon.

Most investigators of clastic dikes concluded that clastic dikes were formed early in the diagenetic process before the sediments were solidified. Price's explanation would require some kind of remobilization of clastic material under high, confining pressure after solidification. The pressure gradient would, under such conditions, be directed upward, but the clastic dikes in Illinois, Iowa, and the Appalachian coal field were obviously filled from above. Intrusion of clastic material (quicksand or quickclay) from below has, however, been reported from several areas (Shrock, 1948). Clastic dikes have also been explained as development of cracks due to slow creep of the coal-forming material on an uneven floor (Wilson, 1916), and as contemporaneous wash-outs (Dzens-Litovskaya, 1954, Pesek, 1965). From England, the origin of clastic dikes during earthquakes has been proposed by Kendall (1919), by Raistrick and Marshall (1939), and by Shirley (1955). Slumping, which can frequently be related to seismic activity (Gregory, 1969; Howard and Lohrengel, 1969; and Büttner,

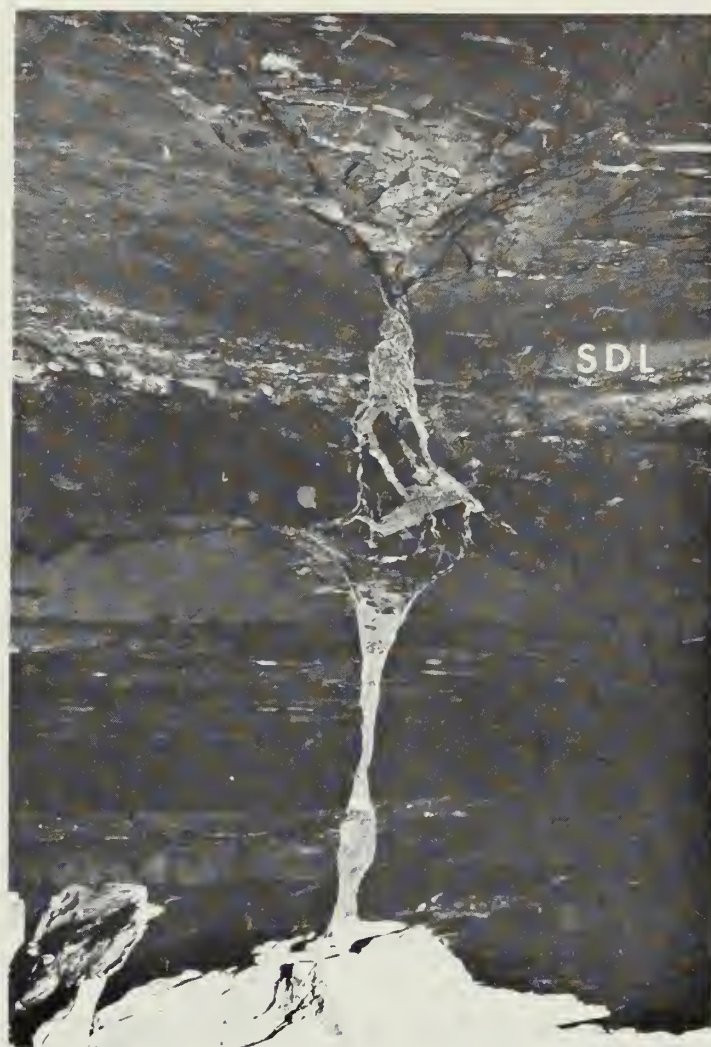


Fig. 7 - This clay dike is related to a large roof fall in a mine entry (No. 5 Coal). Top of coal is near bottom of photo. The St. David Limestone (SDL) is not well developed in this location. The clay dike ends a little above the limestone, but slickensided and polished planes continue upward, disrupting the roof strata and causing hazardous roof conditions.

1969), generally leads to the formation of clastic dikes in the affected strata.

Cady (1942) and Wanless (1952) concluded that the "white top" disturbance of No. 6 Coal formed before the roof sediments were deposited. Cady indicated that cracking may have been caused by dessication, and that the cracks were filled with fine silt, which was either washed or blown in. Wanless related the channel-like appearance of "white top" areas to the development of tidal channels prior to the invasion of the marsh by the sea. It is difficult, however, to understand why dessication cracks or tidal channels should be restricted in their occurrence to No. 6 Coal, and only certain areas within this coal.

CONCLUSIONS

It is the author's opinion that a number of earth movements are recorded in the Pennsylvanian rocks of the Illinois Basin. A prominent earthquake is believed to have occurred shortly after the material making up the No. 6 Coal was deposited, and before any appreciable overburden had accumulated. Over most of the northern and northwestern part of the Illinois coal field, the No. 6 Coal shows severe disturbances of its structure (fig. 8), especially in the upper part of the seam. Another earthquake is believed to have affected the No. 5 Coal and the overlying strata up to approximately 20 to 30 feet (present thickness) in the same part of the state (fig. 8). Clastic dikes extend only from the base of this coal to a little above the St. David Limestone, 3 to 4 feet above the No. 5 Coal. However, slickensided and polished slip planes have been observed in roof falls in an underground mine up to over 20 feet above the coal. The degree of disturbance decreases southward and eastward in both coal seams. The epicenters of the earthquakes must therefore be sought somewhere to the north or northwest of the Illinois Basin.

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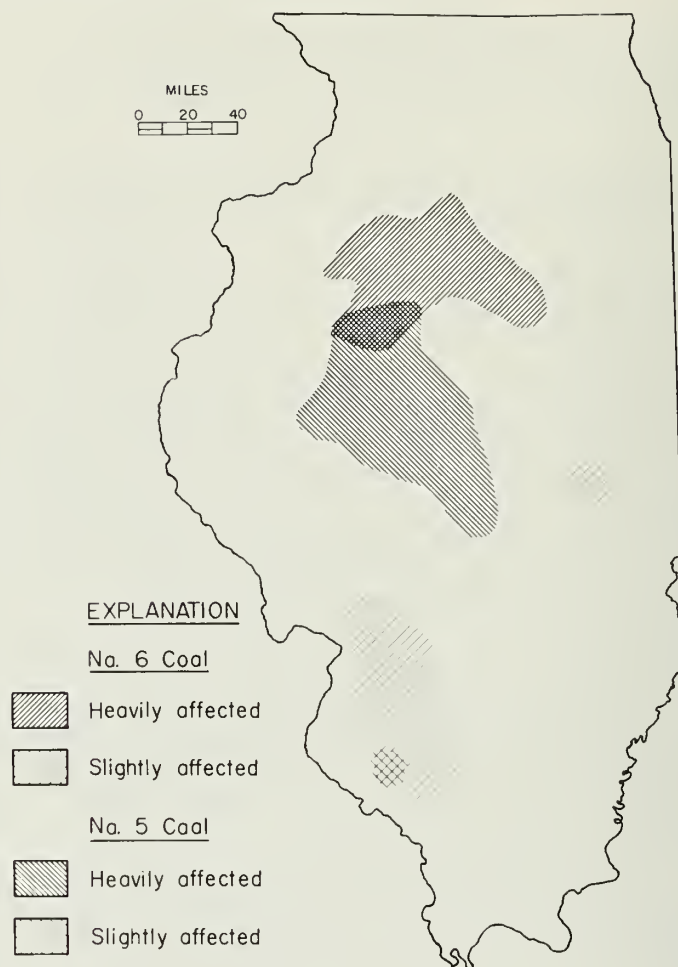


Fig. 8 - Areas in No. 5 and No. 6 Coals which are heavily affected and those which are only slightly affected by clastic dikes (No. 5 Coal), and "white top" and clastic dikes (No. 6 Coal). The areal distribution suggests epicenters for the inferred earthquakes to the north or northwest.

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